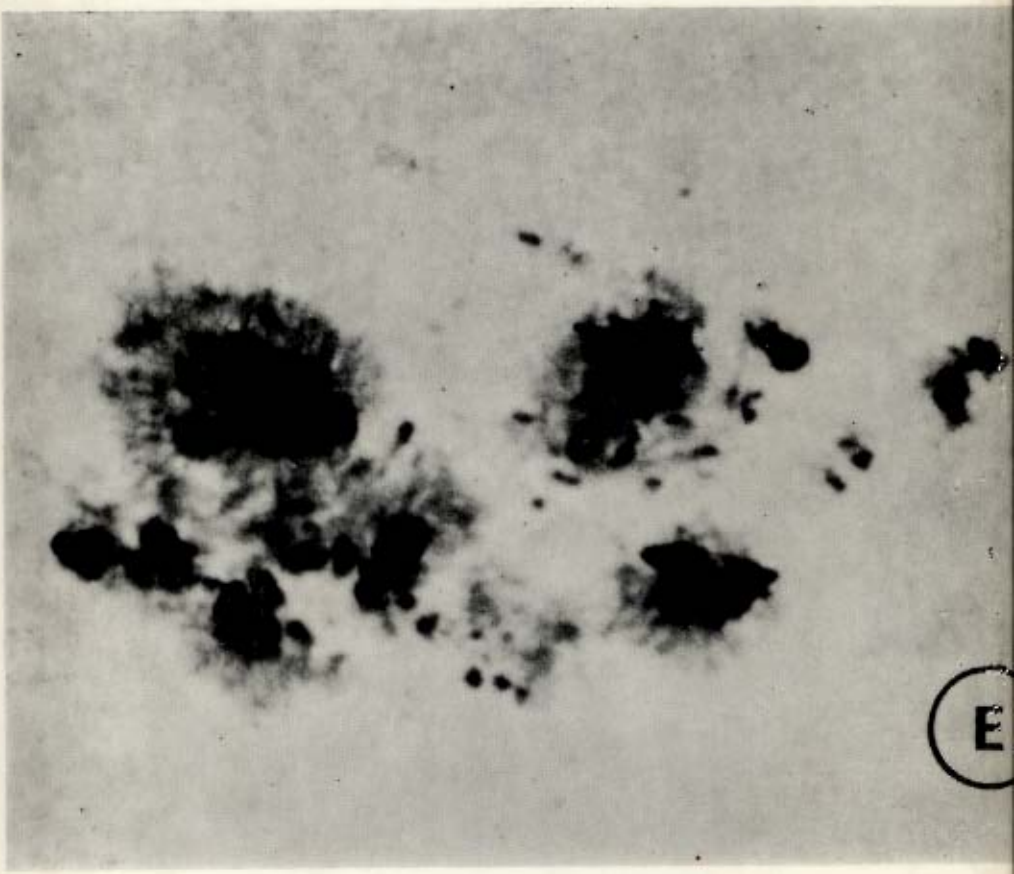
1968 Yearbook of Astronomy

Editor PATRICK MOORE



EYRE & SPOTTISWOODE

YEARBOOK OF ASTRONOMY 1968

EDITED BY
PATRICK MOORE

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Contents

Editorial · vii

Preface · viii

Index to Articles in Previous *Yearbooks* · ix

PART I: EVENTS OF 1968

Notes on the Star Charts · 3

The Star Charts · 6–31

The Planets in 1968 · 32

Phases of the Moon, 1968 · 33

The Planets and the Ecliptic · 34

Notes on the Planets in the Monthly Diagrams · 35

Monthly Notes · 39–92

Eclipses, 1968 · 93

Occultations, 1968 · 93

Comets in 1968 · 94

Meteors in 1968 · 95

Minor Planets in 1968 · 96

Some Events of 1969 · 97

PART II: ARTICLE SECTION

A Simple Home-made Refractor · *T. J. C. A. Moseley* · 101

The Sun · *W. M. Baxter* · 111

Events on the Moon · *B. M. Middlehurst* · 117

Mantle Convection in the Moon · *S. Miyamoto* · 127

The Barwell Meteorite · *H. G. Miles* · 135

The Progress of Meteoritics in Western Australia · *G. J. H. McCall* · 146

The Hertzsprung-Russell Diagram · *R. C. Maddison* · 156

Interstellar Dust · *Iain Nicolson* · 170

Spiral Structure in Galaxies · *P. A. Wayman* · 177

Planetology, or Geology applied to the Planets · *Gennadiy N. Katterfeld* · 185

Recent Advances in Astronomy · *Patrick Moore* · 200

PART III: FOR STELLAR OBSERVERS

Variable Stars · *J. S. Glasby* · 204

Some Interesting Double Stars · 215

Some Interesting Clusters and Nebulæ · 216

PART IV: MISCELLANEOUS

Astronomical Societies · 218

Some Recent Books · 222

Editorial

Once again there is little to say in an Editorial, since the pattern of the 1968 *Yearbook* is exactly the same as it has been in the past. Dr J. G. Porter has made his usual essential contributions, and has been responsible for the whole of Part I apart from some of the additional comments in the monthly notes. I cannot resist noting the international nature of our Article Section this year. Of our contributors, Professor Wayman is Director of the Dunsink Observatory in Eire; Professor Miyamoto, Director of the Kwasan Observatory in Japan; Gennadiy N. Katterfeld is President of the Commission of Planetology in the Academy of Sciences, U.S.S.R.; Professor McCall carries out his researches at the University of Western Australia, Miss Middlehurst hers at the University of Arizona in the United States, while Mr Glasby and Mr Nicolson come from Scotland and Mr Moseley from Northern Ireland. England is represented by Dr Maddison, Mr Baxter and Mr Miles. To all these contributors, and to the publishers, I can only express my sincere thanks.

PATRICK MOORE

The Planetarium,
Armagh, Northern Ireland

Preface

New readers will find that all the information in this *Yearbook* is given in diagrammatic or descriptive form; the positions of the planets may easily be found on the specially designed star charts, while the monthly notes describe the movements of the planets, and give details of other astronomical phenomena that may be observed from these latitudes. The reader who needs more detailed information will find *Norton's Star Atlas* (Gall and Inglis, 21*s*) invaluable, while more precise positions of the planets and their satellites, together with predictions of occultations, meteor showers and periodic comets may be found in the *Handbook* of the British Astronomical Association. A somewhat similar publication is the *Observer's Handbook* of the Royal Astronomical Society of Canada, and American readers will also find details of forthcoming events given from time to time in the pages of the monthly *Sky and Telescope*; this magazine also publishes complete details of all occultations visible in North America. A new quarterly astronomical periodical, *Planetarium*, is now being published from The Armagh Planetarium in Northern Ireland.

Throughout this volume time is expressed in Greenwich Mean Time (Universal Time); that is, Summer Time is ignored, and the 24-hour clock is used, the day beginning at midnight. The star charts are drawn, and the notes are, in general, designed for use in latitude 52 degrees north, but may be used without alteration throughout the British Isles, and (except in the case of eclipses and occultations) in other countries of similar north latitude.

Index to Articles in Previous *Yearbooks*

BAXTER, W. M. *Observing the Sun:* 1963.
—*The Sun in* 1966: 1966.
BEET, E. A. *Astronomy as a Career:* 1963.
BRINTON, HENRY. *A Run-Off Observatory:* 1963.
—*Astronomy and Navigation:* 1964.
—*Measuring the Universe:* 1965.
—*Telescope Drives:* 1966.
—*Sundials:* 1967.
CALVERT, H. R. *Astronomy at the Science Museum:* 1962.
CAMPBELL, D. A. *Astronomical Photography for Amateurs:* 1962.
CATTERMOLE, P. *Selenology: or Geology Applied to the Moon:* 1964.
DALL, H. E. *Eyepieces – a Practical Assessment:* 1963.
—*Cassegrain Reflectors for Amateurs:* 1966.
DE VAUCOULEURS, G. *Problems of Mars:* 1963.
FIELDER, G. *The Craters on Mars:* 1967.
FOX, W. E. *The Great Red Spot on Jupiter:* 1964.
GARSTANG, R. H. *The Structure of the Galaxy:* 1962.
GATLAND, K. W. *The Astronautical Outlook:* 1965.
GOODMAN, J. A. *The Edgewise Presentation of Saturn's Rings:* 1966.
GRIFFIN, R. *Automation in Astronomy:* 1962.
—*Variable Stars:* 1963.
HEY, M. H. *Meteorites and Life:* 1963.
HOLE, G. A. *Telescopic Faults:* 1965.
HYDE, F. W. *The Radio Sun:* 1965.
—*New Horizons:* 1966.
JARRETT, A. H. *Recent Rocket Research:* 1962.
JENNISON, R. C. *Radio and Radar Astronomy:* 1962.

LAURIE, P. S. *Solar Research:* 1962.
—*Harrison, Maskelyne and the Longitude Problem:* 1964.
LINDSAY, E. M. *Quasi-Stellar Objects:* 1967.
MADDISON, R. C. *Image Converters in Astronomy:* 1967.
MILES, H. *With Mariner II to Venus:* 1964.
—*Meteorite Craters:* 1965.
—*Recent Activities in Space:* 1966.
—*The Van Allen Radiation Belts:* 1967.
MIYAMOTO, S. *Clouds in the Atmosphere of Mars:* 1965.
MOORE, PATRICK. *The Origin of the Universe:* 1962.
—*Introduction to Mars:* 1965.
—*Introduction to Saturn:* 1966.
MUIRDEN, J. *A Cycle of Clusters and Nebulæ:* 1965.
—*A Cycle of Double Stars:* 1966.
—*A Cycle of Variable Stars:* 1967.
MURDIN, P. *Stellar Clusters:* 1963.
NICOLSON, IAIN. *Astronomy at British Universities:* 1966.
PEEK, B. M. *The Satellites of Jupiter:* 1962.
PORTER, J. G. *Astronomy and Space Research:* 1963.
—*The Distance of the Sun:* 1964.
—*Short-Period Comets:* 1964.
RONAN, C. A. *Planetary Nebulæ:* 1964.
SISSON, G. M. *The Isaac Newton Telescope:* 1967.
VETTERLEIN, J. *Double and Binary Stars:* 1962.
WARNER, B. *Peculiarities among the Cool Stars:* 1965.
WILDEY, H. *Telescope Mountings:* 1964.
WRIGHT, H. N. D. *The Surface of Saturn:* 1964.

PART ONE

Events of 1968

Monthly Charts and Astronomical Phenomena

Notes on the Star Charts

The stars, together with the Sun, Moon and planets, seem to be set on the surface of the celestial sphere, which appears to rotate about the Earth from east to west. Since it is impossible to represent a curved surface accurately on a plane, any kind of star map is bound to contain some form of distortion. But it is well known that the eye can endure some kinds of distortion better than others, and it is particularly true that the eye is most sensitive to deviations from the vertical and horizontal. For this reason the star charts given in this volume on pages 6 to 29 have been designed to give a true representation of vertical and horizontal lines, whatever may be the resulting distortion in the shape of a constellation figure. It will be found that the amount of distortion is, in general, quite small, and is only obvious in the case of large constellations such as Leo and Pegasus, when these appear at the top of the charts, and so are drawn out sideways.

The charts show all stars down to the fourth magnitude, together with a number of fainter stars which are necessary to define the shape of a constellation. There is no standard system for representing the outlines of the constellations, and triangles and other simple figures have been used to give outlines which are easy to follow with the naked eye. The names of the constellations are given, together with the proper names of the brighter stars. The apparent magnitudes of the stars are indicated roughly by using four different sizes of dots, the larger dots representing the bright stars.

There are four such charts at each opening, and these give a complete coverage of the sky up to an altitude of $62\frac{1}{2}$ degrees; there are twelve such sets to cover the entire year. The upper two charts show the southern sky, south being at the centre; the coverage is 200 degrees in azimuth, from a little north of east

(top left) to a little north of west (top right). The two lower charts show the northern sky, from a little south of west (lower left) to a little south of east (lower right). There is thus an overlap east and west.

The charts have been drawn for a latitude of 52 degrees, but may be taken without appreciable error to apply to all parts of the British Isles. They will also be equally suitable for any other part of the world having a north latitude of about 52 degrees – e.g. parts of Europe and Asia, and Canada. In such cases the times given must be taken as local time, and not G.M.T., which applies only to the British Isles.

Because the sidereal day is shorter than the solar day, the stars appear to rise and set about four minutes earlier each day, which amounts to two hours in a month. Hence the twelve sets of charts are sufficient to give the appearance of the sky throughout the day at intervals of two hours, or at the same time of night at monthly intervals throughout the year. The actual range of dates and times when the stars on the charts are visible is indicated at the top of each page. This information is summarized in the following table, which gives the number of the star chart to be used for any given month and time.

G.M.T.	16^h	18^h	20^h	22^h	0^h	2^h	4^h	6^h
January	10	11	12	1	2	3	4	5
February		12	1	2	3	4	5	6
March			2	3	4	5	6	
April			3	4	5	6		
May			4	5	6	7		
June			5	6	7			
July			6	7	8	9		
August			7	8	9	10	11	
September		7	8	9	10	11	12	
October		8	9	10	11	12	1	
November	8	9	10	11	12	1	2	3
December	9	10	11	12	1	2	3	4

The charts are drawn to scale, and estimates of altitude and azimuth may be made from them. These values will necessarily be mere approximations, since no observer will be exactly on the meridian of Greenwich at 52 degrees latitude, but they will generally serve for the identification of stars and planets. The horizontal measurements, marked at every ten degrees, give the azimuths (or true bearings) measured from the north round through east (90 degrees), south (180 degrees), and west (270 degrees). The vertical measurements, similarly marked, give the altitudes of the stars up to $62\frac{1}{2}$ degrees.

The ecliptic is drawn as a broken line on which the longitude is marked at every ten degrees; the positions of the planets at any time are then easily found by reference to the table immediately following the star charts on page 32.

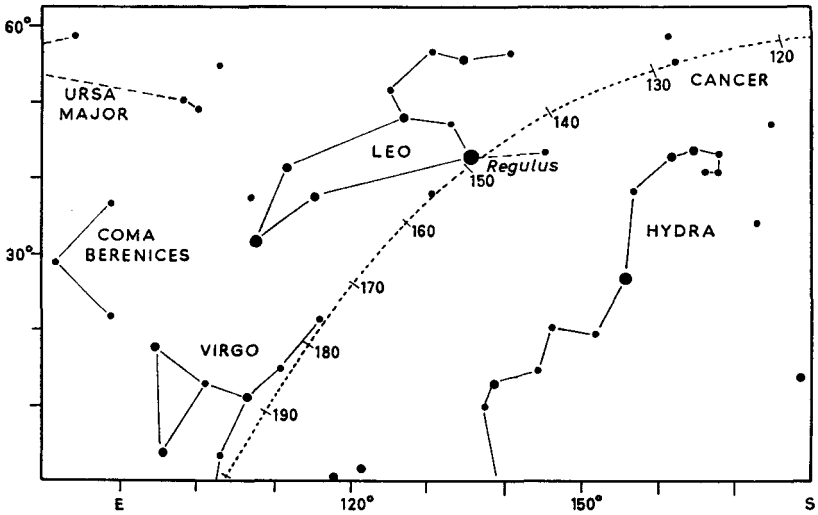
There is a curious illusion that stars at an altitude of 60 degrees or more are actually overhead, and the beginner may often feel that he is leaning over backwards in trying to see them. These high-altitude stars, being nearer the pole, move more slowly across the sky, and a different kind of map may therefore be used. These overhead stars are given separately on pages 30 and 31, the entire year being covered at one opening. Each of the four maps shows the overhead stars at times which correspond to those of three of the main star charts. The position of the zenith in latitude 52 degrees is indicated by a cross, and this cross also marks the centre of a circle which is 35 degrees from the zenith, and which therefore indicates an altitude of 55 degrees; there is thus a small overlap with the main charts.

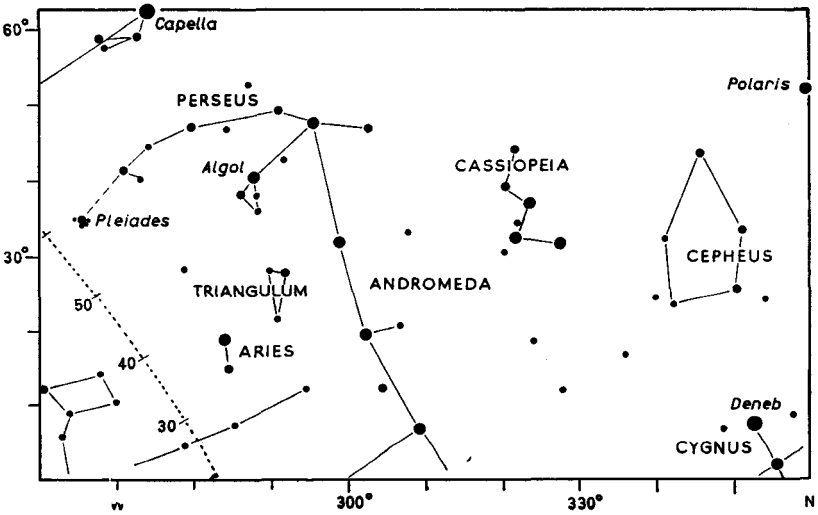
The broken line leading from north to south is numbered to indicate the corresponding main chart. Thus on page 30 the N-S line numbered 6 is to be regarded as an extension of the S line of chart 6 on pages 16 and 17, and at the top of these pages are given dates and times which are appropriate.

The scale is the same on all the charts (approximately 25 degrees to the inch), but the overhead stars are plotted as a true map on a conical projection, and are not simple graphs like the main charts.

2L

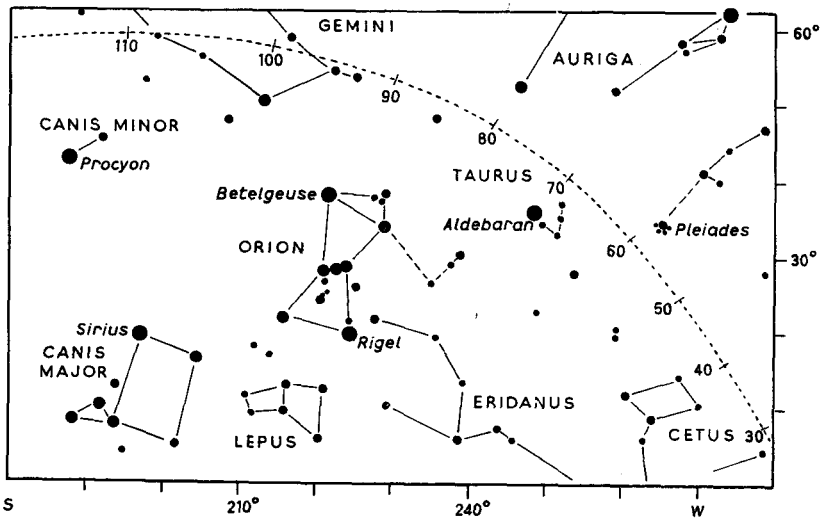
November 6 at	5h	November 21 at	4h
December 6 at	3h	December 21 at	2h
January 6 at	1h	January 21 at	midnight
February 6 at	23h	February 21 at	22h
March 6 at	21h	March 21 at	20h

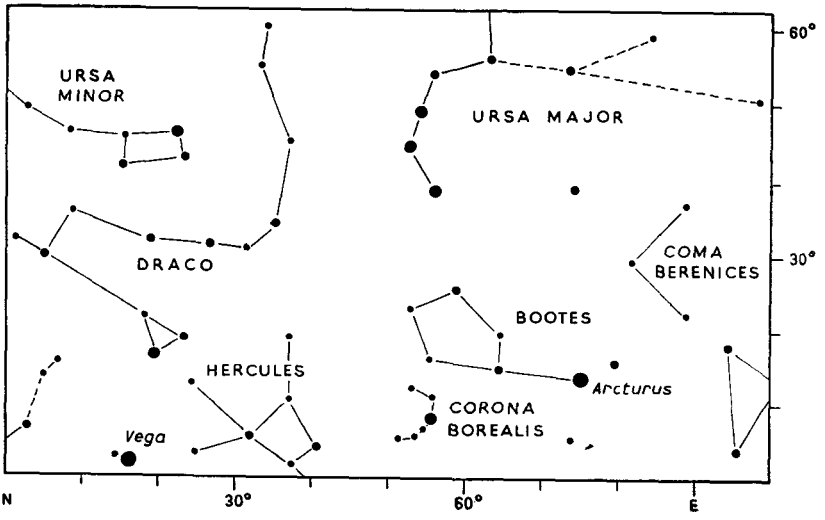




November 6 at 5h	November 21 at 4h
December 6 at 3h	December 21 at 2h
January 6 at 1h	January 21 at midnight
February 6 at 23h	February 21 at 22h
March 6 at 21h	March 21 at 20h

2R





3L

December 6 at	5^h	December 21 at	4^h
January 6 at	3^h	January 21 at	2^h
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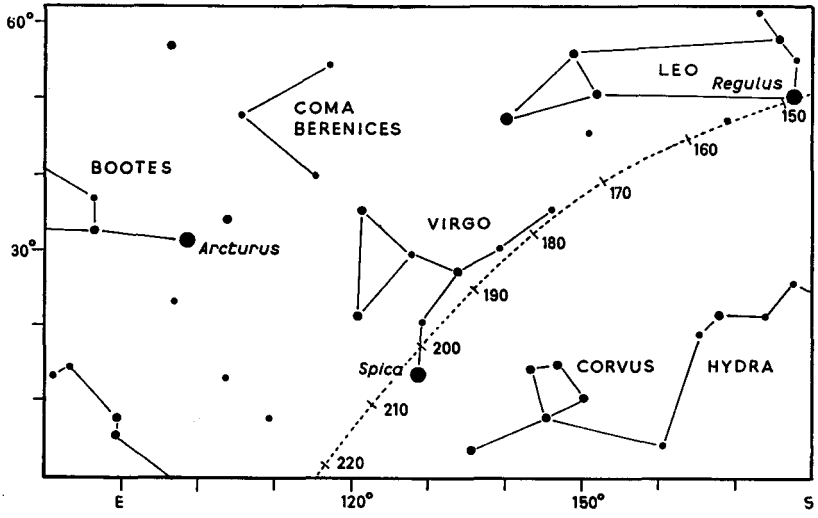
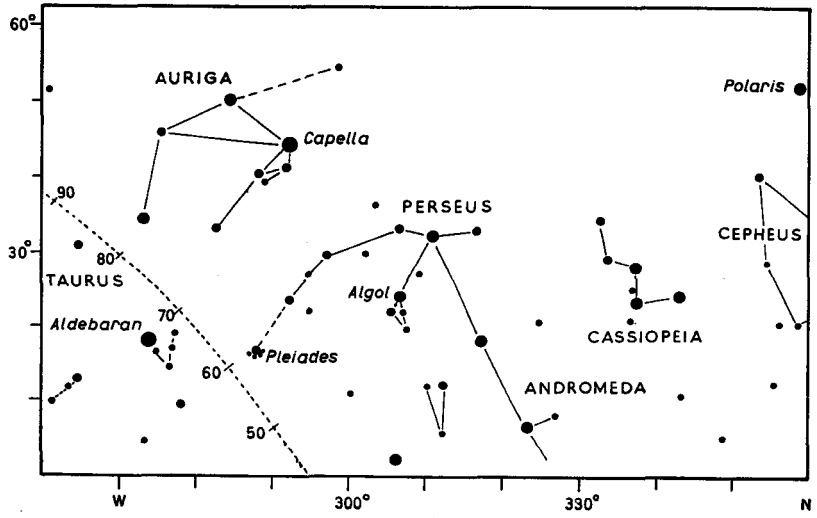
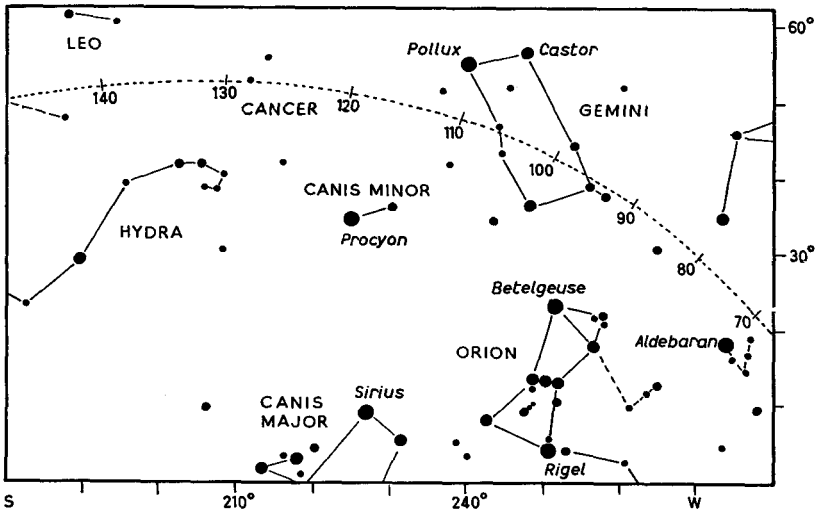
April 6 at	21^h	April 21 at	20^h

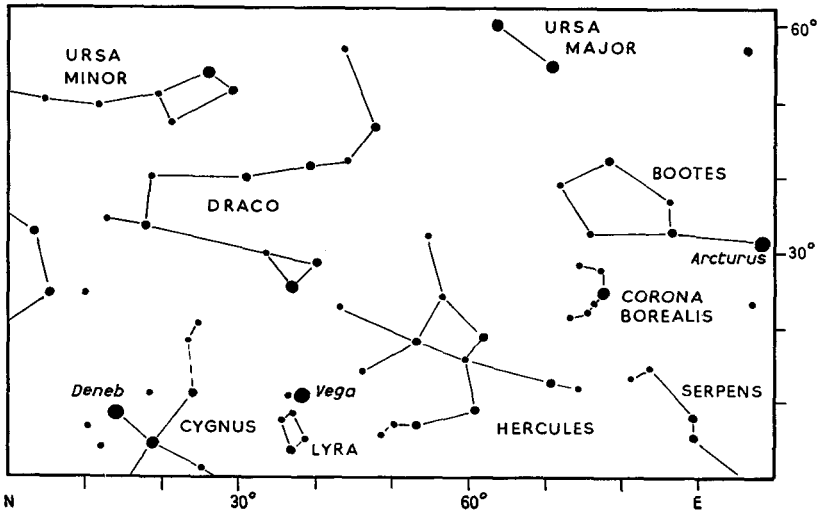




December 6 at	5h	December 21 at	4h
January 6 at	3h	January 21 at	2h
February 6 at	1h	February 21 at	midnight
March 6 at	23h	March 21 at	22h
April 6 at	21h	April 21 at	20h

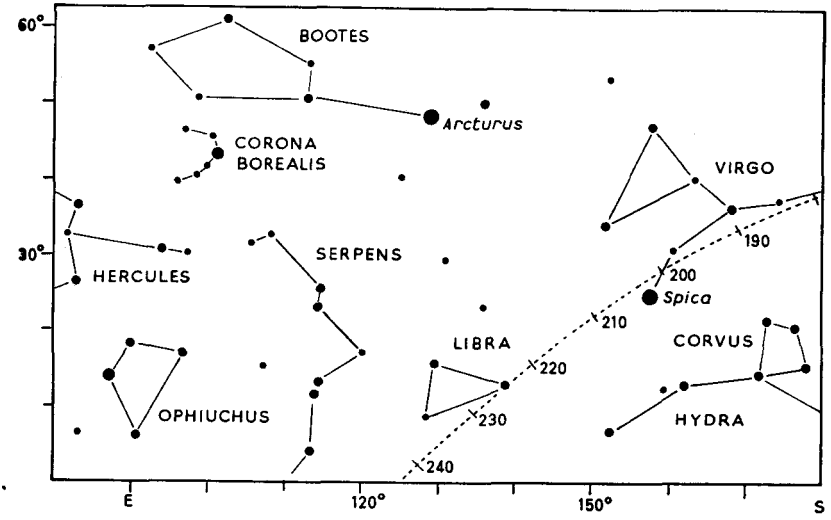
3R

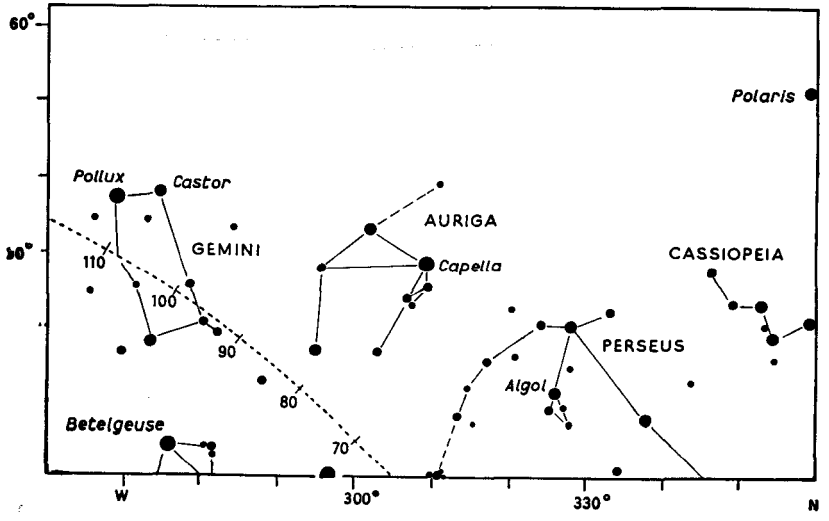




4L

January 6 at 5h	January 21 at 4h
February 6 at 3h	February 21 at 2h
March 6 at 1h	March 21 at midnight
April 6 at 23h	April 21 at 22h
May 6 at 21h	May 21 at 20h





January 6 at 5h	January 21 at 4h	**4R**
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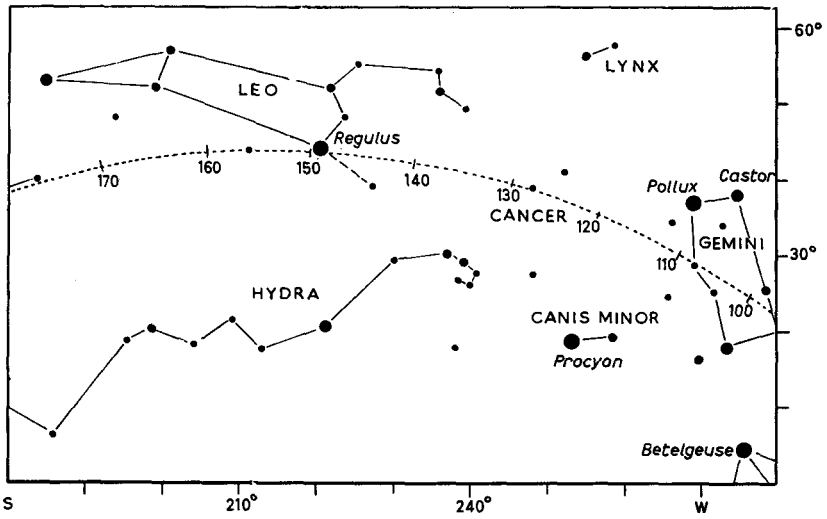
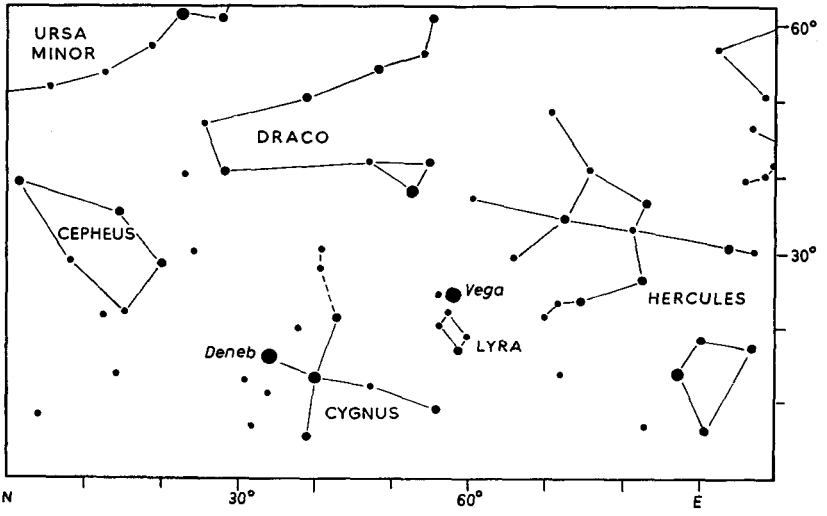
May 6 at 21h	May 21 at 20h	





5L

January 6 at 7h	January 21 at 6h
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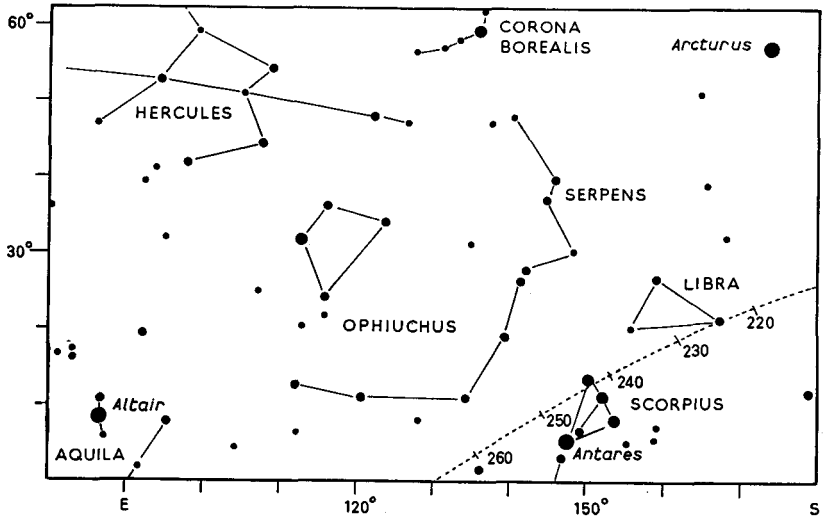

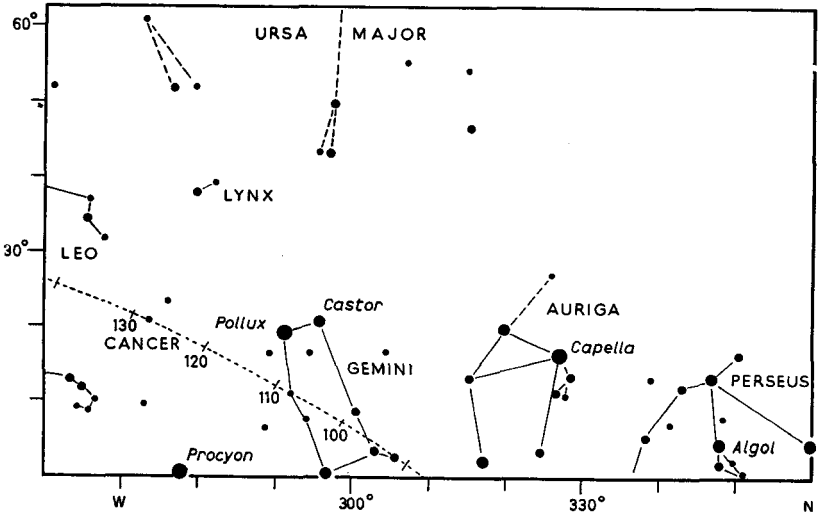

January 6 at	7h	January 21 at	6h
February 6 at	5h	February 21 at	4h
March 6 at	3h	March 21 at	2h
April 6 at	1h	April 21 at	midnight
May 6 at	23h	May 21 at	22h

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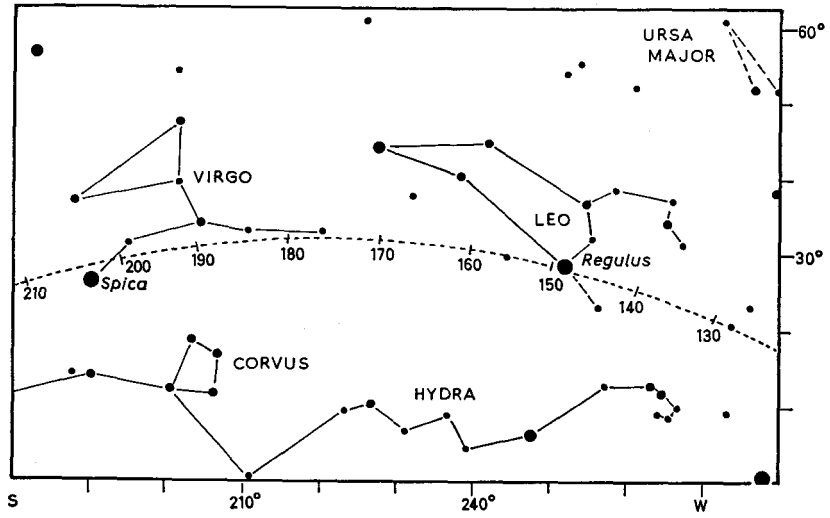

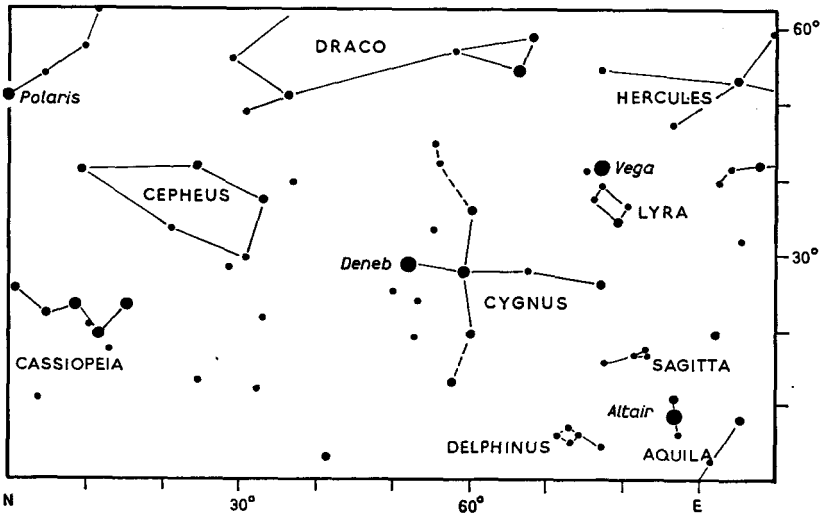

6L

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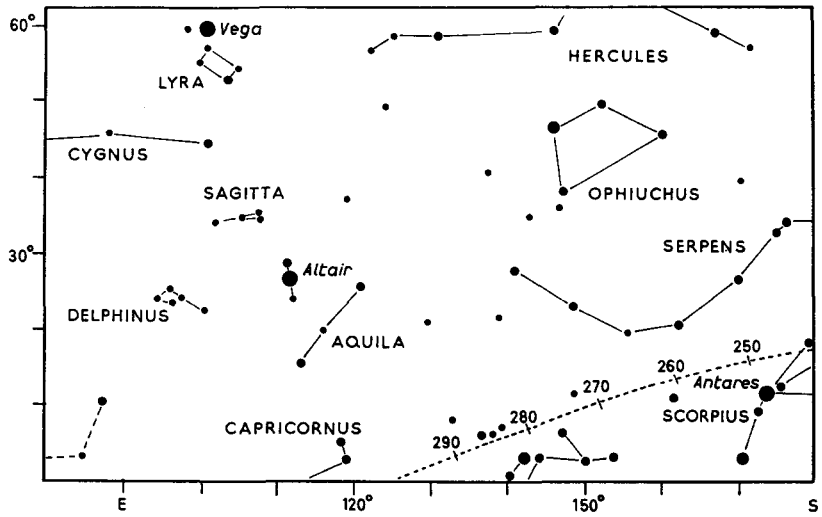
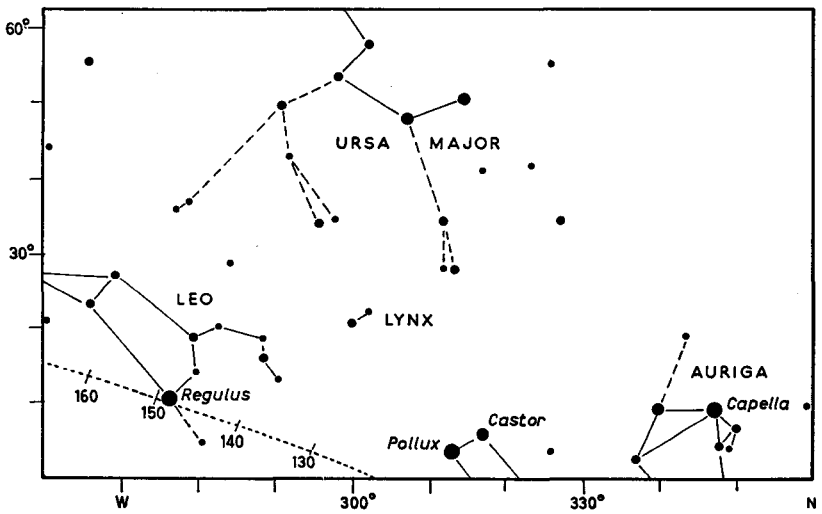
May 6 at 1h	May 21 at midnight
June 6 at 23h	June 21 at 22h
July 6 at 21h	July 21 at 20h





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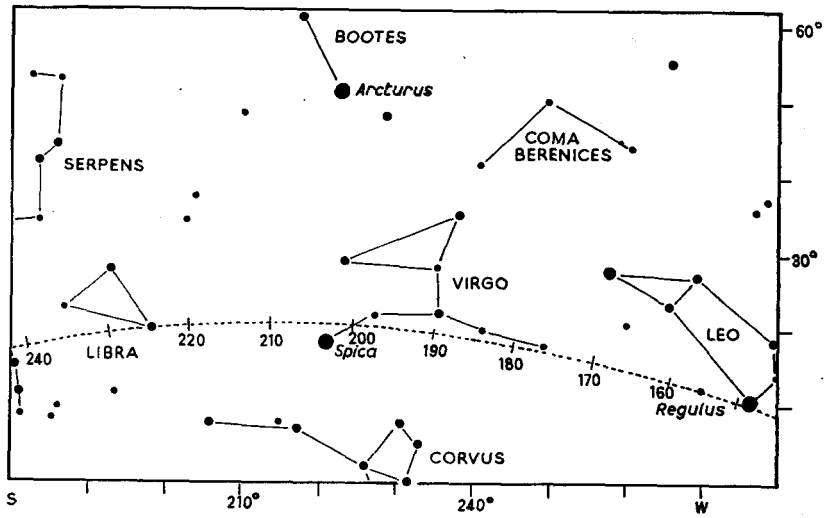
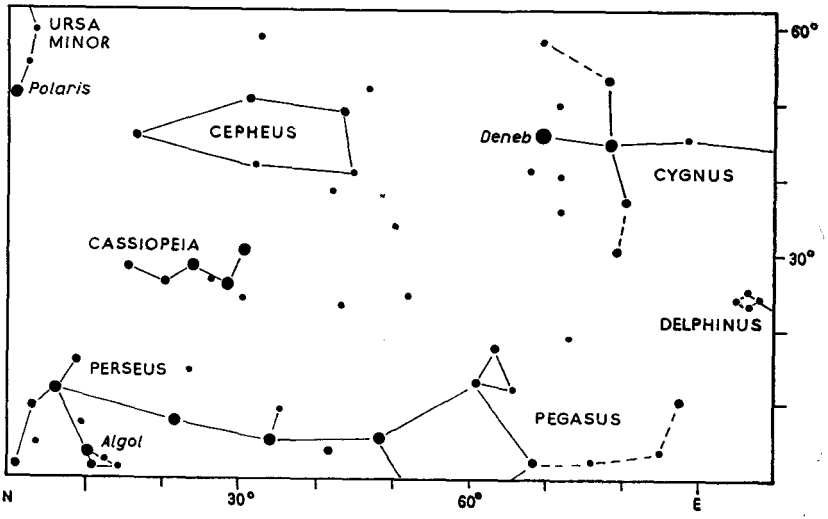
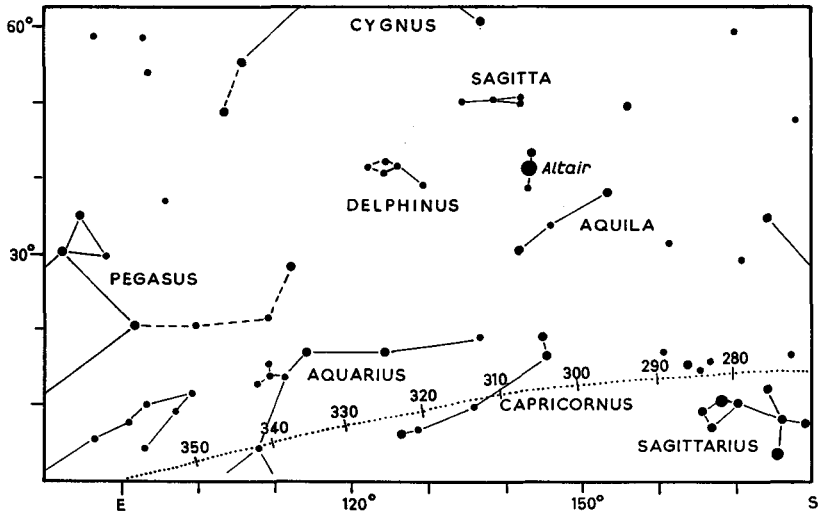
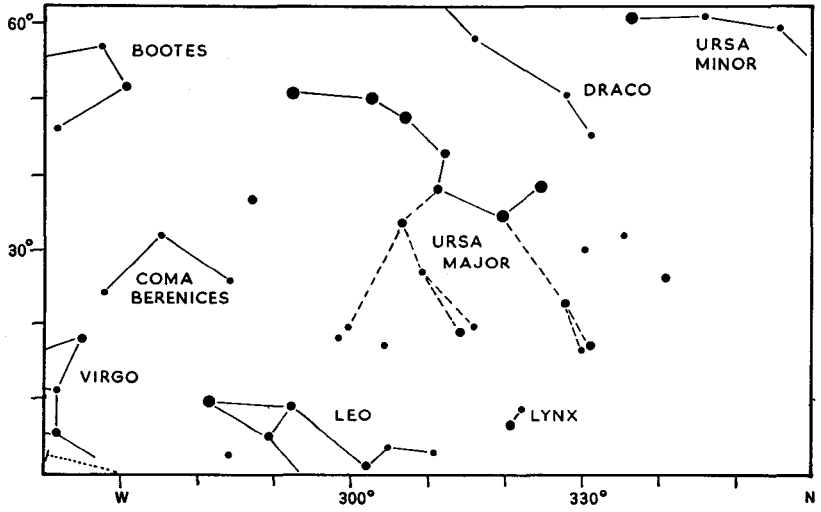




7L

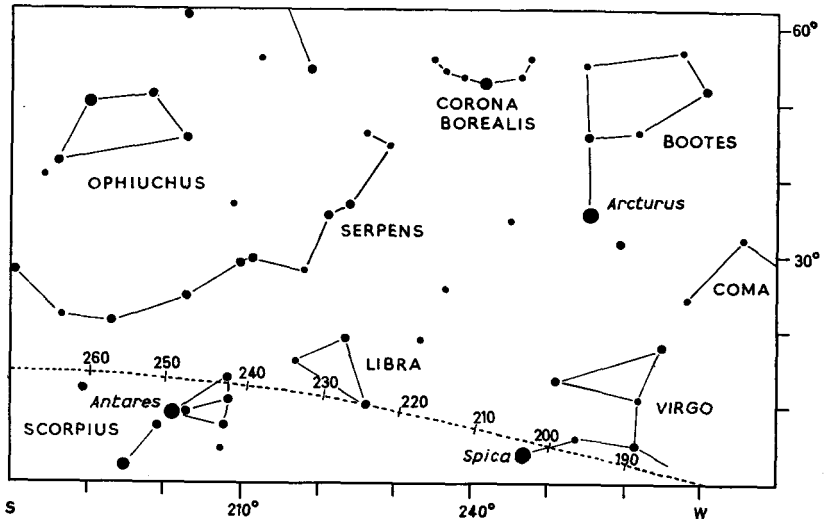
May 6 at 3h	May 21 at 2h
June 6 at 1h	June 21 at midnight
July 6 at 23h	July 21 at 22h
August 6 at 21h	August 21 at 20h
September 6 at 19h	September 21 at 18h

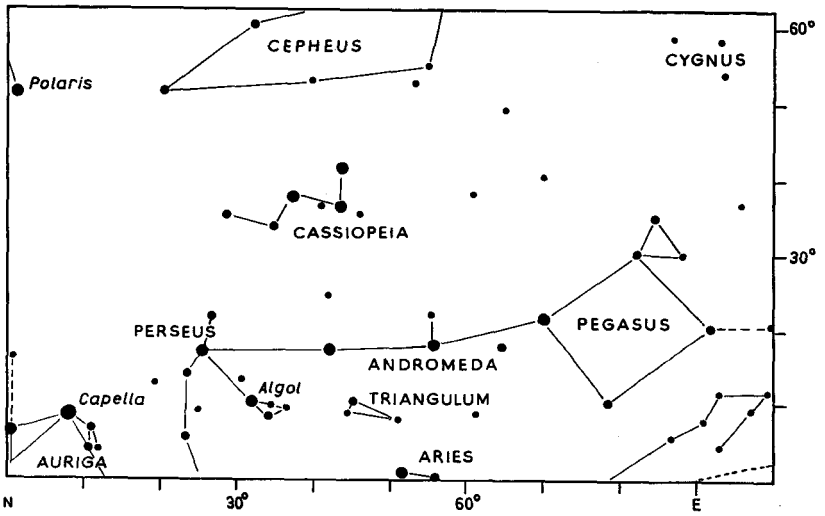




May 6 at 3h	May 21 at 2h
June 6 at 1h	June 21 at midnight
July 6 at 23h	July 21 at 22h
August 6 at 21h	August 21 at 20h
September 6 at 19h	September 21 at 18h

7R





8L

July 6 at 1h	July 21 at midnight
August 6 at 23h	August 21 at 22h
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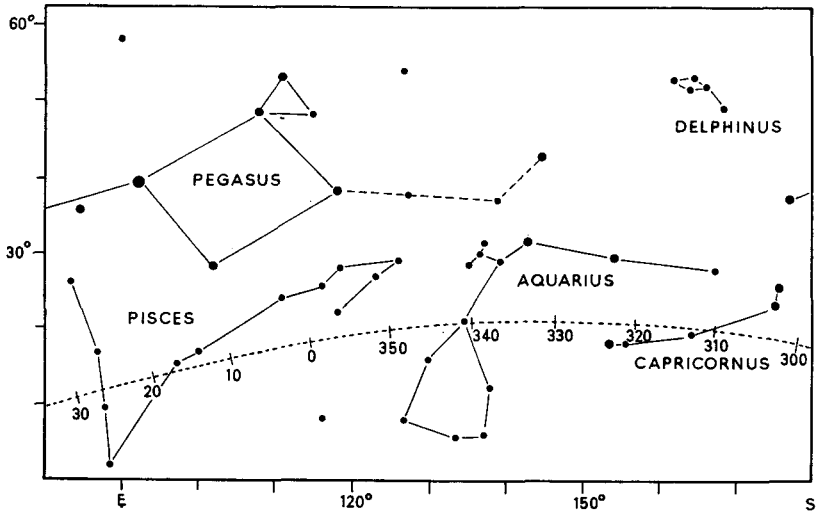
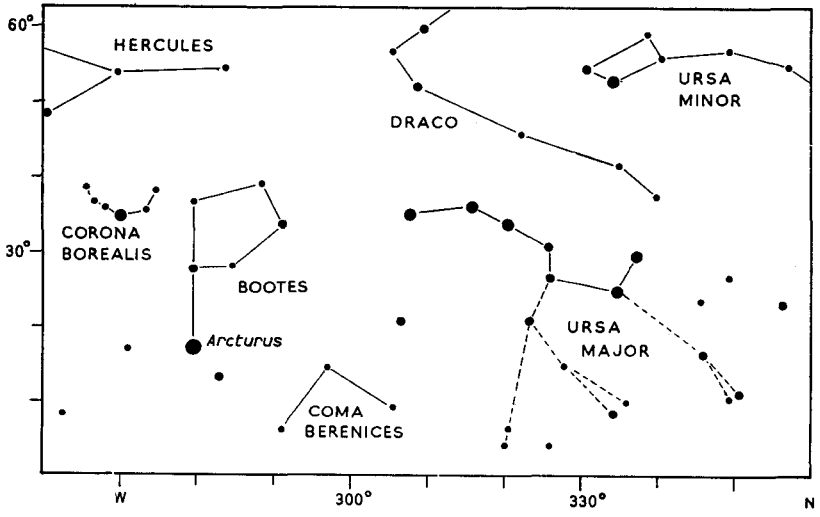
October 6 at 19h	October 21 at 18h
November 6 at 17h	November 21 at 16h





July 6 at 1h
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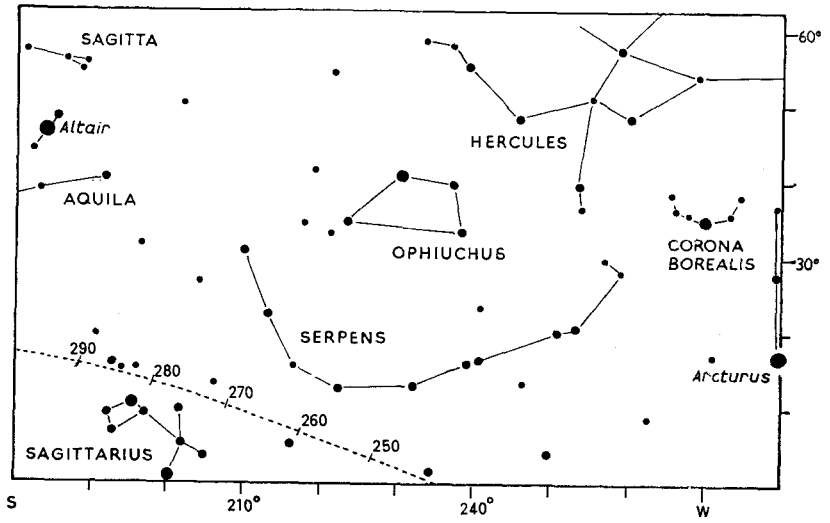
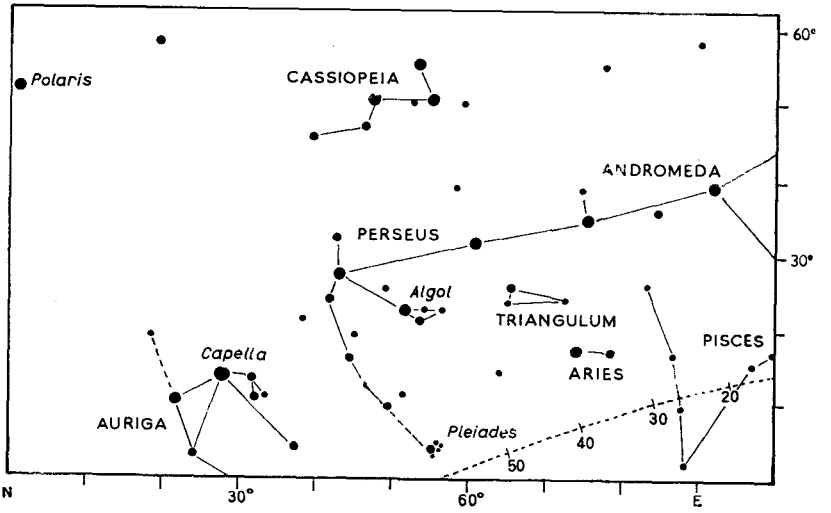
September 6 at 21h
October 6 at 19h
November 6 at 17h

July 21 at midnight
August 21 at 22h
September 21 at 20h
October 21 at 18h
November 21 at 16h

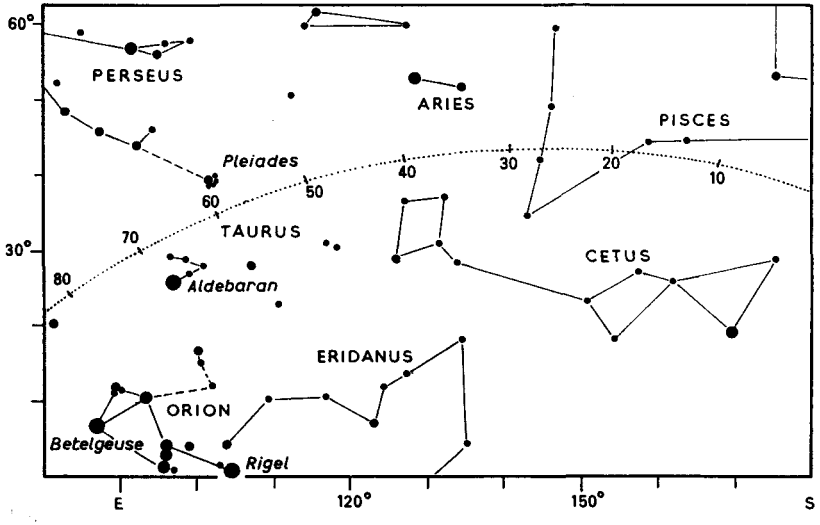
8R

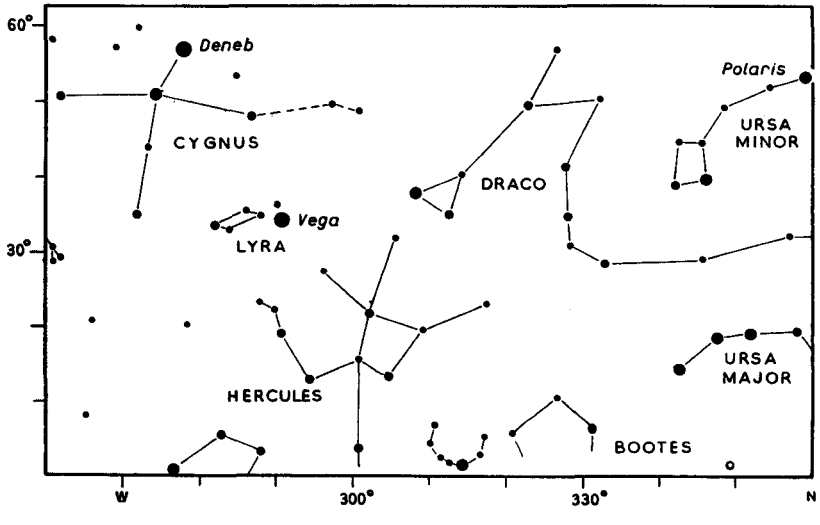




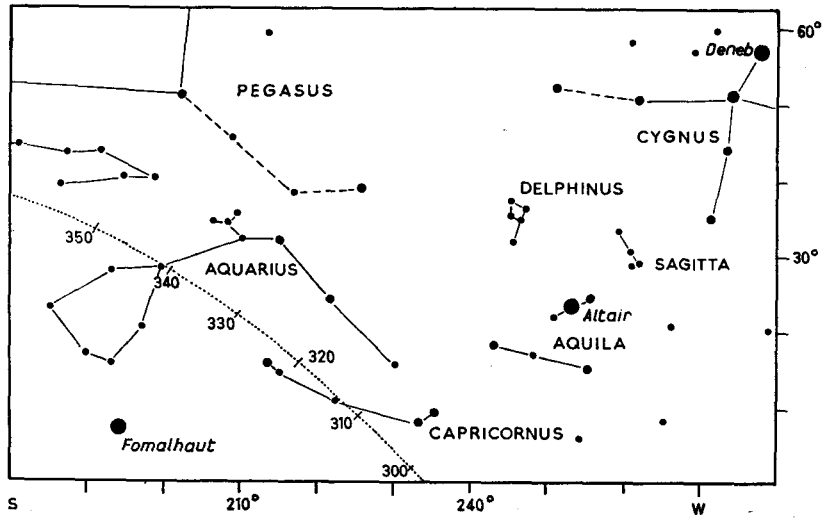
10L

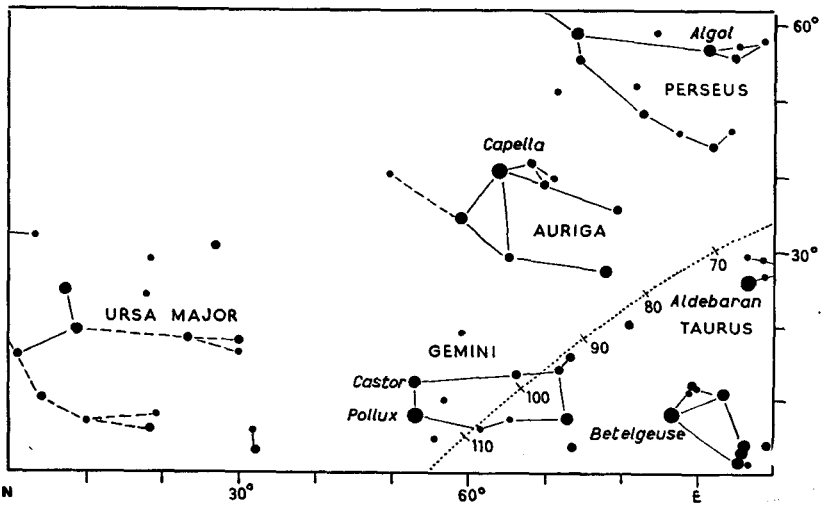
August 6 at 3h	August 21 at 2h
September 6 at 1h	September 21 at midnight
October 6 at 23h	October 21 at 22h
November 6 at 21h	November 21 at 20h
December 6 at 19h	December 21 at 18h





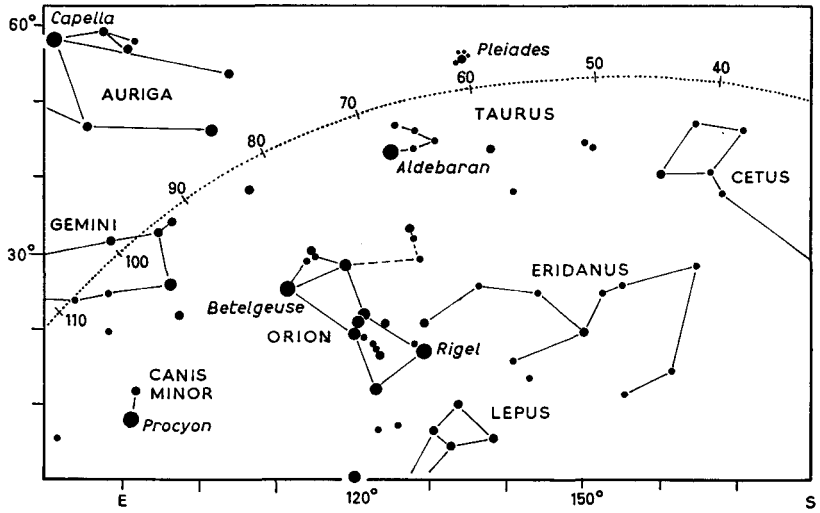
August 6 at 3h	August 21 at 2h	**10R**
September 6 at 1h	September 21 at midnight	
October 6 at 23h	October 21 at 22h	
November 6 at 21h	November 21 at 20h	
December 6 at 19h	December 21 at 18h	

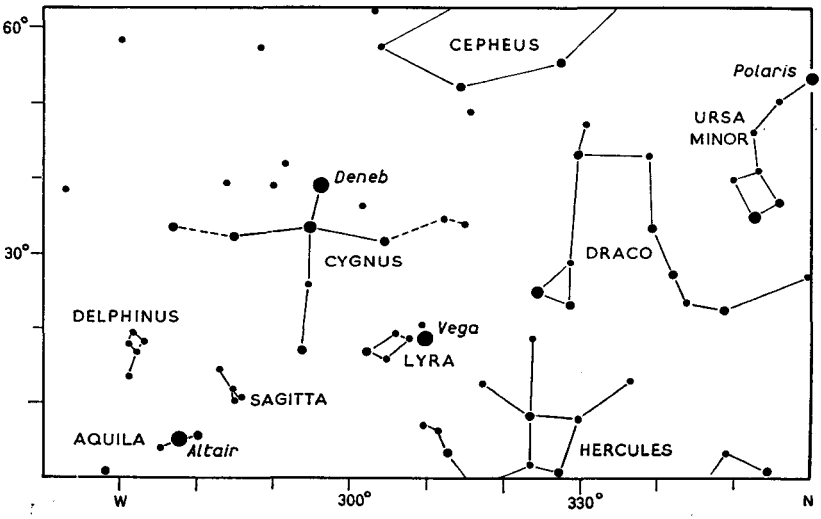




11L

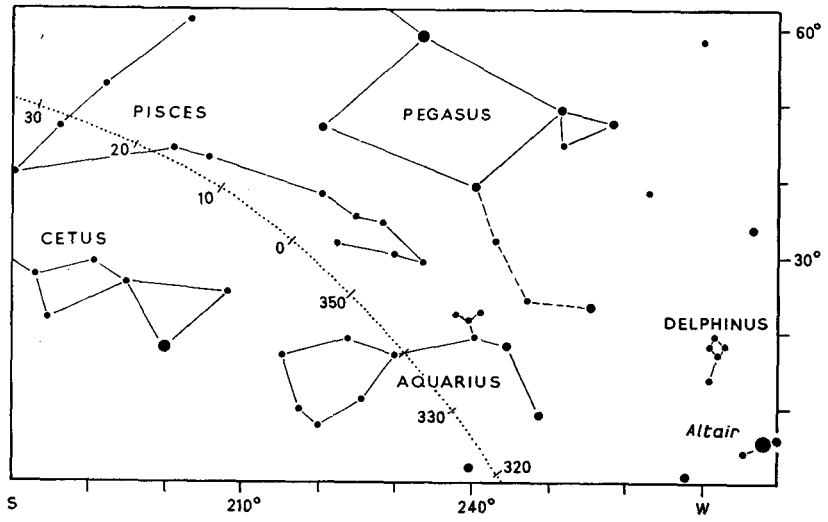
September 6 at 3h	September 21 at 2h
October 6 at 1h	October 21 at midnight
November 6 at 23h	November 21 at 22h
December 6 at 21h	December 21 at 20h
January 6 at 19h	January 21 at 18h

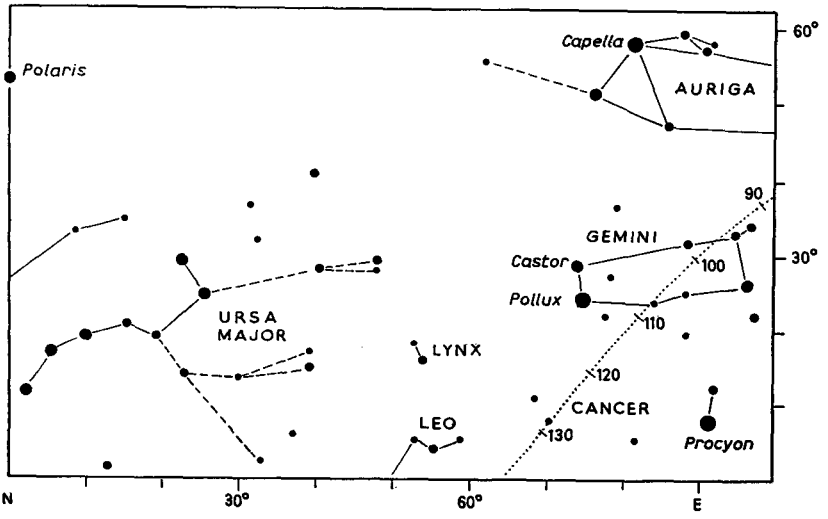




September 6 at 3h	September 21 at 2h
October 6 at 1h	October 21 at midnight
November 6 at 23h	November 21 at 22h
December 6 at 21h	December 21 at 20h
January 6 at 19h	January 21 at 18h

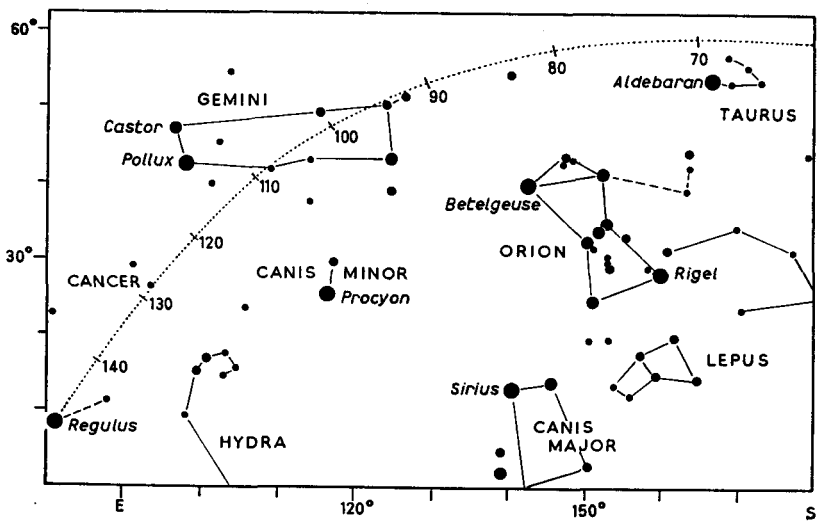
11R

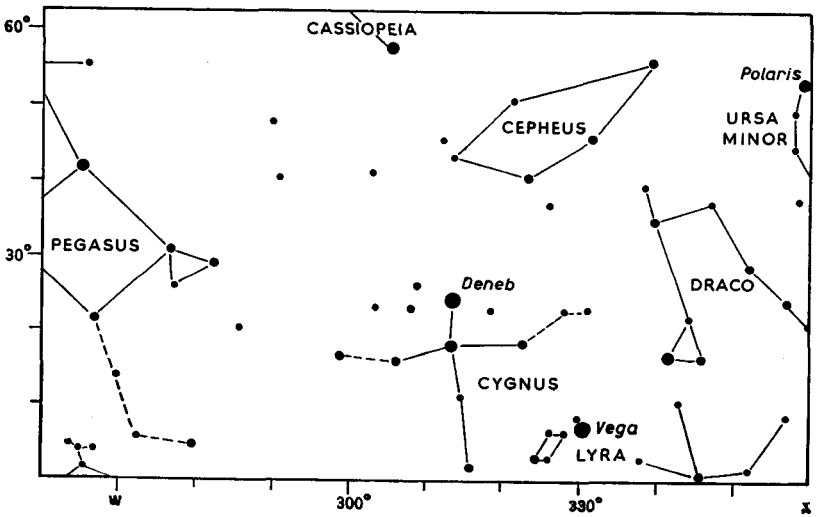




12L

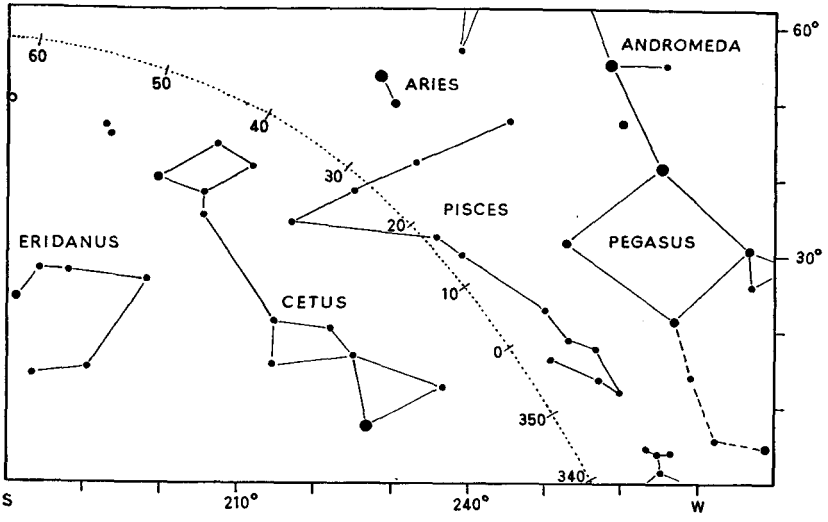
October 6 at 3h	October 21 at 2h
November 6 at 1h	November 21 at midnight
December 6 at 23h	December 21 at 22h
January 6 at 21h	January 21 at 20h
February 6 at 19h	February 21 at 18h

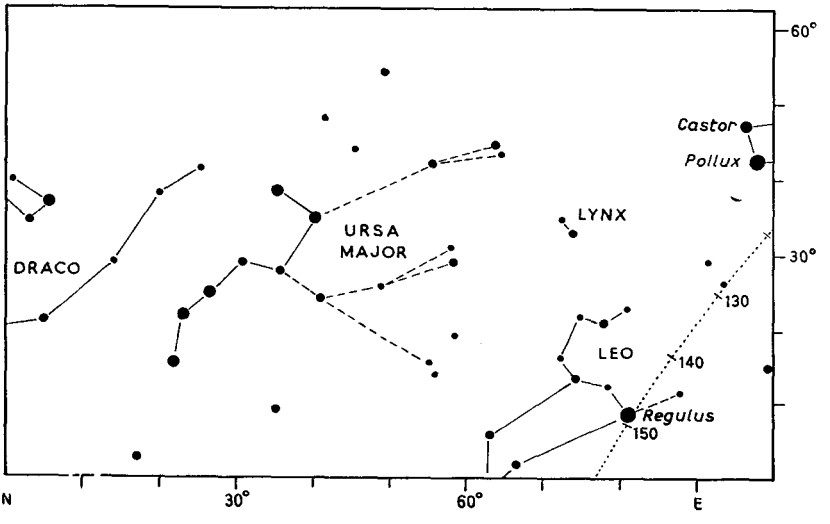


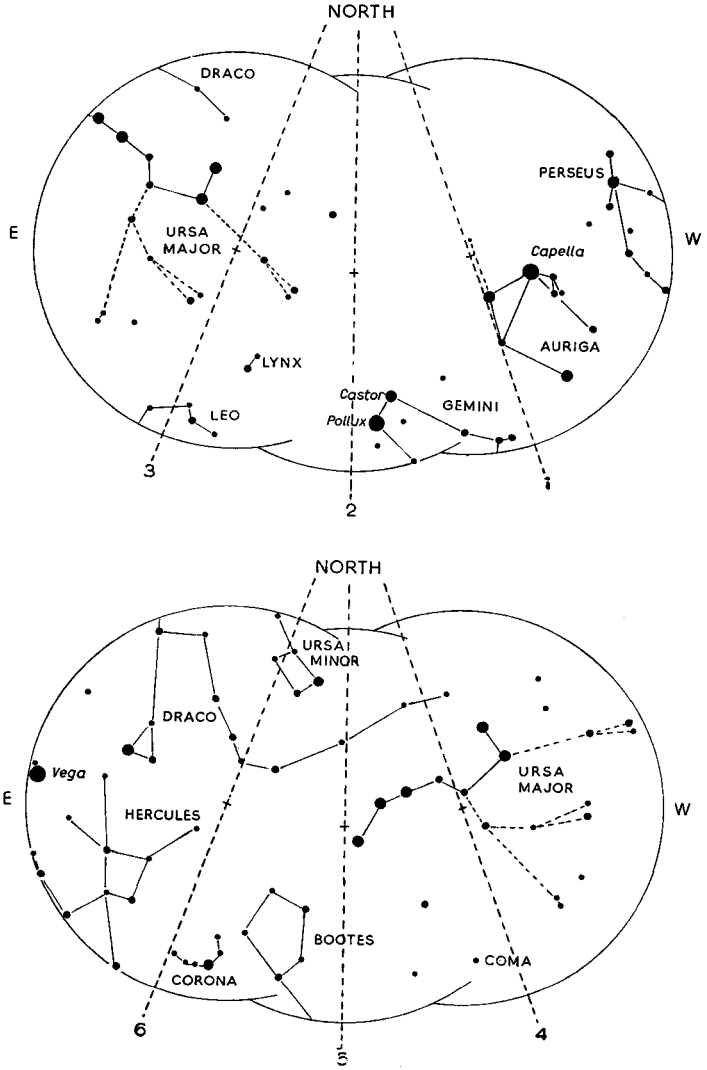


October 6 at	3h	October 21 at	2h
November 6 at	1h	November 21 at	midnight
December 6 at	23h	December 21 at	22h
January 6 at	21h	January 21 at	20h
February 6 at	19h	February 21 at	18h

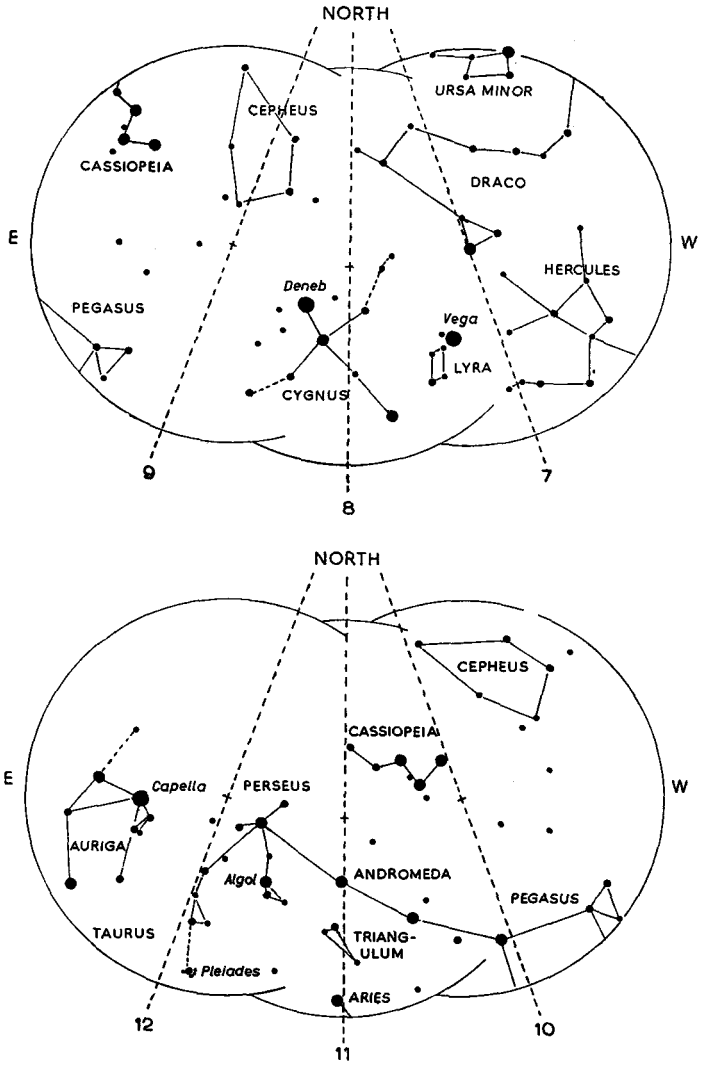
12R







Overhead stars



Overhead stars

The Planets in 1968

DATE		*Venus*	*Mars*	*Jupiter*	*Saturn*	*Uranus*	*Neptune*
January	6	245°	328°	156°	7°	180°	236°
	21	263°	339°	155°	8°	179°	237°
February	6	282°	352°	153°	10°	179°	237°
	21	301°	3°	151°	11°	179°	237°
March	6	318°	14°	149°	13°	178°	237°
	21	337°	25°	148°	14°	177°	237°
April	6	357°	36°	147°	16°	177°	237°
	21	16°	47°	146°	18°	176°	236°
May	6	34°	58°	147°	20°	176°	236°
	21	52°	69°	148°	22°	175°	235°
June	6	71°	80°	149°	23°	175°	235°
	21	90°	90°	151°	25°	176°	235°
July	6	108°	100°	154°	26°	176°	234°
	21	127°	110°	157°	26°	176°	234°
August	6	147°	120°	160°	27°	177°	234°
	21	165°	130°	163°	26°	178°	234°
September	6	185°	140°	166°	26°	179°	234°
	21	203°	150°	169°	25°	180°	235°
October	6	221°	159°	173°	24°	181°	235°
	21	240°	169°	176°	23°	182°	236°
November	6	259°	179°	179°	22°	183°	236°
	21	277°	188°	181°	21°	183°	237°
December	6	296°	197°	183°	20°	184°	237°
	21	314°	205°	185°	20°	184°	238°
Conjunction:							
Superior		June 20	June 21	Sept. 9	Apr. 5	Sept. 22	Nov. 18
Opposition:		—	—	Feb. 20	Oct. 15	Mar. 17	May 16

Mercury moves so quickly among the stars that it is not possible to indicate its position on the star charts at a convenient interval. The monthly notes must be consulted for the best times at which the planet may be seen.

The positions of the other planets are given in the table on the opposite page. This gives the apparent longitudes on dates which correspond to those of the star charts, and the position of the planet may at once be found near the ecliptic at the given longitude.

Examples:

(1) *What is the bright planet seen in the eastern sky just before sunrise on November 5?*
Assuming the time to be about 5^h, the table on page 4 shows that the appropriate star chart is number 2, and from this the longitude of the planet must be about 180°. The table opposite shows that both Mars and Jupiter are in this position, but Jupiter must be the brighter of the two. The actual circumstances are described in the November notes.

(2) *Where may Saturn be found on December 14 at 22^h?*
From the table opposite, the longitude of Saturn at this time is seen to be about 20°, and star chart number 12 shows that the planet will be found in the south-west at about 35° altitude.

Phases of the Moon, 1968

New Moon				*First Quarter*				*Full Moon*				*Last Quarter*			
	d	h	m		d	h	m		d	h	m		d	h	m
Jan.	29	16	29	Jan.	7	14	23	Jan.	15	16	11	Jan.	22	19	38
Feb.	28	06	56	Feb.	6	12	20	Feb.	14	06	43	Feb.	21	03	28
Mar.	28	22	48	Mar.	7	09	20	Mar.	14	18	52	Mar.	21	11	07
Apr.	27	15	21	Apr.	6	03	28	Apr.	13	04	52	Apr.	19	19	35
May	27	07	30	May	5	17	54	May	12	13	05	May	19	05	44
June	25	22	25	June	4	04	47	June	10	20	13	June	17	18	14
July	25	11	49	July	3	12	42	July	10	03	18	July	17	09	11
Aug.	23	23	57	Aug.	1	18	34	Aug.	8	11	32	Aug.	16	02	13
Sept.	22	11	08	Aug.	30	23	35	Sept.	6	22	07	Sept.	14	20	31
Oct.	21	21	44	Sept.	29	05	07	Oct.	6	11	46	Oct.	14	15	05
Nov.	20	08	02	Oct.	28	12	40	Nov.	5	04	25	Nov.	13	08	53
Dec.	19	18	19	Nov.	26	23	30	Dec.	4	23	07	Dec.	13	00	49
				Dec.	26	14	14								

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The Planets and the Ecliptic

The paths of the planets about the Sun all lie close to the plane of the ecliptic, which is marked for us in the sky by the apparent path of the Sun among the stars, and is shown on the star charts by a broken line. The Moon and planets will always be found close to this line, never departing from it by more than about 7 degrees. Thus the planets are most favourably placed for observation when the ecliptic is well displayed, and this means that it should be as high in the sky as possible. This avoids the difficulty of finding a clear horizon, and also overcomes the problem of atmospheric absorption, which greatly reduces the light of the stars. Thus a star at an altitude of 10 degrees suffers a loss of 60 per cent of its light, which corresponds to a whole magnitude; at an altitude of only 4 degrees, the loss may amount to two magnitudes.

The position of the ecliptic in the sky is therefore of great importance, and since it is tilted at about 23½ degrees to the equator, it is only at certain times of the day or year that it is displayed to the best advantage. It will be realized that the Sun (and therefore the ecliptic) is at its highest in the sky at noon in midsummer, and at its lowest at noon in midwinter. Allowing for the daily motion of the sky, these times lead to the fact that the ecliptic is highest at midnight in winter, at sunset in the spring, at noon in summer, and at sunrise in the autumn. Hence these are the best times to see the planets. Thus, if Venus is an evening star, in the western sky after sunset, it will be seen to best advantage if this occurs in the spring, when the ecliptic is high in the sky and slopes down steeply to the north-west. This means that the planet is not only higher in the sky, but will remain for a much longer period above the horizon. For similar reasons, a morning star will be seen at its best on autumn mornings before sunrise, when the ecliptic is high in the east. The outer planets, which can come to opposition and are then in the south at midnight, are best seen when opposition occurs in the winter months. Clearly the summer is the least favourable time to observe the planets, for the ecliptic is always low in the sky on summer nights.

Notes on the Planets in the monthly diagrams

The following general notes on observing the planets are followed by detailed month-by-month accounts of the behaviour of the planets, and of other interesting phenomena. These monthly notes include diagrams of the planetary orbits, and of the apparent movements of the planets at favourable times of the year. Additional notes on other astronomical phenomena will be found on the following pages.

The monthly diagrams of the orbits of the planets are intended to give a picture of the way in which the planets move about the Sun during the month. These diagrams are similar to those that were given many years ago in the old *English Mechanic*, and which were also adopted for some time in the *Journal* of the B.A.A. The motions of the planets are all anti-clockwise, and the movement during the month is indicated by the thickened line; the longitudes are measured from the Equinox, marked 0°. It is difficult to show all the orbits to scale, since the distance of Pluto from the Sun is about a hundred times that of Mercury. For this reason, only the orbits of the inner planets (Mercury to Mars) are shown to scale, those of the outer planets being merely suggested in the diagrams. A line drawn from the Earth to any other planet will give a rough idea of the apparent longitude of that body, but a more accurate value can be obtained from the table on page 30, and this will enable the position of the planet to be found on the monthly star charts.

The inferior planets, Mercury and Venus, move in smaller orbits than that of the Earth, and so are always seen near the Sun. They are most obvious at the times of greatest angular distance from the Sun (greatest elongation), which may reach 28 degrees for Mercury, or 47 degrees for Venus. They are then seen as evening stars in the western sky after sunset (at eastern elongations) or as morning stars in the eastern sky before sunrise (at western elongations). The succession of phenomena, conjunctions and

elongations, always follows the same order, but the intervals between them are not equal. Thus if either planet is moving round the far side of its orbit its motion will be to the east, in the same direction in which the Sun appears to be moving. It therefore takes much longer for the planet to overtake the Sun – that is, to come to superior conjunction – than it does when moving round to inferior conjunction, between Sun and Earth. The intervals given in the following table are average values; they remain fairly constant in the case of Venus, which travels in an almost circular orbit. In the case of Mercury, however, conditions vary widely because of the great eccentricity and inclination of the planet's orbit.

			Mercury	*Venus*
Inferior conj.	to	Elongation West	22 days	72 days
Elongation West	to	Superior conj.	36 days	220 days
Superior conj.	to	Elongation East	36 days	220 days
Elongation East	to	Inferior conj.	22 days	72 days

The greatest brilliancy of Venus always occurs about a month *before* greatest western elongation (as a morning star), or a month *after* greatest eastern elongation (as an evening star). No such rule can be given for Mercury, because its distance from Sun and Earth can vary over a wide range.

Mercury is not likely to be seen unless a clear horizon is available; it is seldom seen as much as 10 degrees above the horizon in the twilight sky. In general it may be said that the most favourable times for seeing Mercury as an evening star will be in spring, some days before greatest eastern elongation; in autumn it may be seen as a morning star some days after greatest western elongation.

Venus is the brightest of the planets, and may be seen on occasions in broad daylight. Like Mercury, it is alternately a morning and an evening star, and will be highest in the sky when it is a morning star in autumn, or an evening star in spring. Venus is seen to best advantage when it comes to greatest eastern elongation in June; it is then well north of the Sun in the spring months and is a brilliant object in the sunset sky over a long period.

The superior planets, which travel in orbits larger than that of the Earth, differ from Mercury and Venus in that they can be seen opposite the Sun in the sky. The superior planets are morning stars after conjunction with the Sun, rising earlier each day until they come to opposition. They will then be in the south at midnight, and visible all night. After opposition, they are evening stars, setting earlier each evening until they set in the west with the Sun at the next conjunction. The interval between conjunctions or between oppositions is greatest for Mars (over two years). At the time of opposition, the planet is nearest the Earth, and therefore at its brightest. This change in brightness is most noticeable with Mars, whose distance from the Earth can vary considerably; the other superior planets are at such great distances that there is very little change in brightness from one opposition to another. The effect of altitude is, however, of importance, for at a December opposition the planet will be among the stars of Taurus or Gemini, and can then be at an altitude of more than 60 degrees in southern England. At a summer opposition, when the planet is in Sagittarius, it may only rise to about 15 degrees above the southern horizon, and so make a less impressive appearance.

Mars, whose orbit is appreciably eccentric, comes nearest to the Earth at an opposition at the end of August; it may then be brighter even than Jupiter, but rather low in the sky in Aquarius. These favourable oppositions occur every fifteen or seventeen years (1924, 1941, 1956, 1973), but in this country the planet is probably better seen at an opposition in the autumn or winter, when it is higher in the sky. Oppositions of Mars occur at an average interval of 780 days, and during this time the planet makes a complete circuit of the sky.

Jupiter is always a bright planet, and comes to opposition a month later each year, having moved, roughly speaking, from one Zodiacal constellation to the next.

Saturn moves much more slowly than Jupiter, and may remain in the same constellation for several years. The brightness of Saturn depends on the aspect of its rings, as well as on the distance

from Earth and Sun. The rings are now opening, and the planet is growing brighter at each opposition.

Uranus, *Neptune* and *Pluto* are hardly likely to attract the attention of observers without adequate instruments, but some notes on their present positions in the sky will be found in the March and May notes.

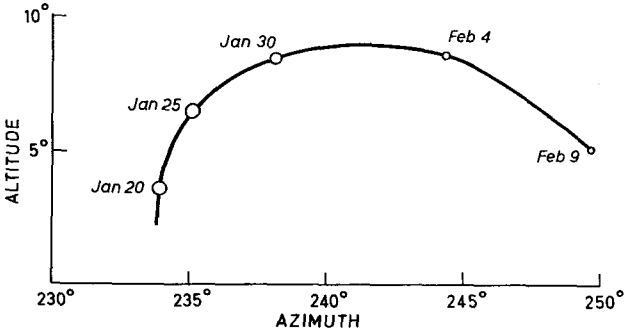
MONTHLY NOTES, 1968

January

Full Moon: January 15 *New Moon:* January 29

Earth is at perihelion (nearest to the Sun) on January 4, its distance from the Sun being then 91,400,000 miles.

Mercury is at greatest eastern elongation on January 31 (18 degrees), and this, together with the May elongation, are the only favourable occasions during the year on which this planet may be seen as an evening star. The diagram shows the changes in altitude and azimuth (true bearing from the north through east, south and west) of Mercury on successive evenings when the Sun is 6 degrees below the horizon; this will be about 35 minutes after sunset. The sizes of the circles give an approximate indication of the expected brightness of the planet; it will be noticed that Mercury is much brighter before the date of greatest elongation.



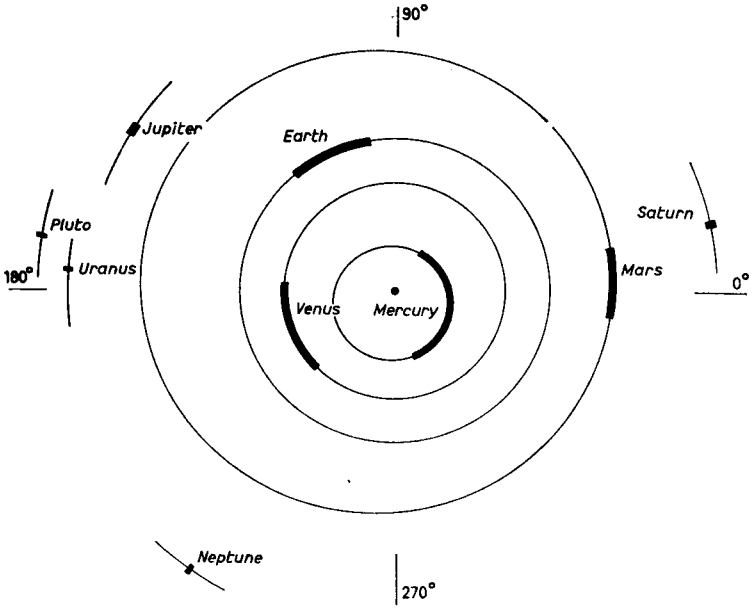
Mercury, January

Venus is a morning star in the south-east before dawn. It rises more than three hours before the Sun at the beginning of the month, but moves rapidly in towards the Sun. Venus was at greatest western elongation in November of last year, and the next

eastern elongation is in 1969 January, so that the planet is not a very impressive object in 1968.

Mars is an evening star, setting in the south-west in mid-evening. The planet is moving rapidly from Capricornus into Aquarius (see diagram, page 45), becoming fainter (magnitude +1·2 to +1·4) as its distance increases. There is no opposition of Mars in 1968, and the planet will not be a very brilliant object during the year.

Jupiter is approaching opposition and is a brilliant object, rising in mid-evening a little north of east. It forms a striking group with the well-known Sickle of Leo, and is easily recognized since it is far brighter (magnitude −1·9 to −2·0) than *Regulus* (magnitude +1·3).



Planetary Orbits in January

Saturn is an evening star (magnitude +1·1), setting about midnight at the beginning of the month, and is in the south at sunset at the end of January. Having just crossed the equator, Saturn is moving north and east in Pisces, and will remain in this constellation throughout the year. The planet will be seen near the crescent Moon on the evening of January 6.

An occultation of *Antares* by the Moon occurs in the morning of January 25. The Moon, four days before New Moon, will occult the star at $11^h\ 08^m$, but observation of this event will call for a good telescope. *Antares* is $4\frac{1}{2}$ degrees south of the ecliptic (see diagram on page 64) and is occulted in this manner over a period of 69 successive months every 18 years.

Synodic Periods of the Planets. During 1968 there are oppositions of Jupiter, Saturn, Uranus, Neptune and Pluto – as indeed there are in almost every year. With Mars, the situation is different. There has been no opposition since the spring of 1967, and the next will not occur until 1969 May 31, because the synodic period of Mars – 780 days – is much longer than that of any other planet.

The synodic period is the mean interval between successive oppositions. To explain what is meant, let us first consider Pluto, which moves round the Sun at a mean distance of more than 3,500,000,000 miles (though its orbit is unusually eccentric, and at its closest it can come within the orbit of Neptune). As well as having a large orbit, Pluto is slow-moving. In one year, the time taken for the Earth to go once round the Sun, Pluto covers only a tiny fraction of its orbit – so that the Sun, Earth and Pluto are lined up every $366\frac{3}{4}$ days. Having been right round the Sun in $365\frac{1}{4}$ days, the Earth takes only an extra day and a half to catch up with Pluto.

With the closer planets, more time is required; the synodic periods for Neptune, Uranus, Saturn and Jupiter are respectively $367\frac{1}{2}$, $369\frac{3}{4}$, 378, and 399 days – so that, for instance, oppositions of Jupiter occur about 34 days later in each year; the opposition of 1968 February follows that of 1967 January, and there will also be oppositions in 1969 March, 1970 April, 1971 May and so on.

Mars is a special case. Its orbital velocity is comparable with that of the Earth, and the synodic period is therefore a great deal longer. Oppositions of Mars do not occur every year; thus there were oppositions in 1963, 1965 and 1967, but there will be none in 1968 – and following the opposition of 1969, 1970 will be another 'blank year' so far as Mars is concerned.

Of course, Mars will not be invisible throughout 1968. At the start of the year it is still an evening star, and by Christmas it will rise at about 2 a.m., so that it will be prominent during the later part of the night. However, it will be a long way away, and not even large telescopes will show much upon its disk. It must be admitted that observers of Mars must resign themselves to inactivity all through 1968.

Occultations of Stars. The occultation of *Antares* on January 25 will be interesting to watch, even though it will not be an easy observation; it will occur during broad daylight.

When the Moon occults a star, the disappearance is much too sudden to be timed – and in fact it may be regarded as instantaneous, even though this is not literally true. One moment, the star is seen shining with its full brilliance; the next, it has completely vanished. There is no gradual fading as the Moon's limb sweeps over it. For one thing, a star appears as a point of light, and not a measurable disk. Secondly, there is no layer of atmosphere round the Moon's edge. Were there any atmosphere of sufficient density to cause visible effects, the star would seem to flicker and fade for some seconds before disappearing – as does actually happen on the rare occasions when the planet Venus occults a star.

This simple fact was one of the early proofs that the Moon has no atmosphere comparable with our own. Even an atmosphere with a ground density of 1/1000 of that of the Earth's air would produce obvious effects upon a star before occultation. Nowadays, it is known that the true density of the lunar atmosphere is far less than this; even the value of 1/10,000 of that of the Earth's air, given more than 15 years ago by the Russian astronomer, Y. Lipsky, has been shown to be a gross over-estimate. If we say that the

Moon is an airless world, we are not far wrong, even though it is now believed that a trace of atmosphere may exist.

Extinction. During January evenings, several brilliant stars are well placed. It is interesting to compare *Rigel*, in the 'foot' of Orion, with *Capella*, in Auriga. The two are almost exactly equal; *Capella* is measured as one-tenth of a magnitude the brighter, which is negligible by naked-eye standards. Yet from Britain and the United States, *Capella* will look much more brilliant. During winter evenings, *Capella* is almost overhead; *Rigel*, which lies south of the celestial equator, is much lower down, and some of its glory is lost by 'extinction', due to the fact that its light is coming to us through a deeper layer of the Earth's atmosphere. A star which is 20 degrees above the horizon will lose almost half a magnitude, while at one degree altitude the loss is as much as 3 magnitudes. Only above 45 degrees altitude may extinction be neglected for practical purposes. A comparison between *Rigel* and *Capella* will show how marked the effect is.

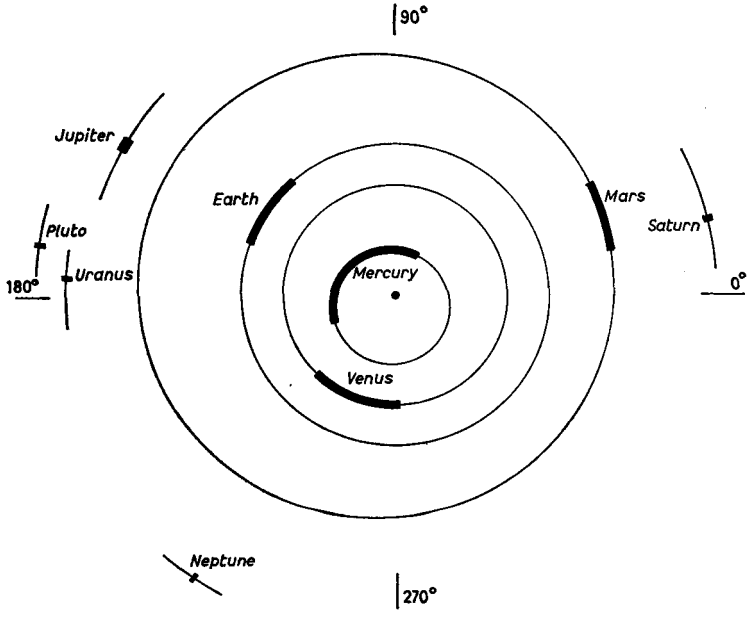
February

Full Moon: February 14 *New Moon:* February 28

Mercury may be visible in the south-west at sunset for the first few days of the month (see January notes), but moves rapidly in towards inferior conjunction on February 15.

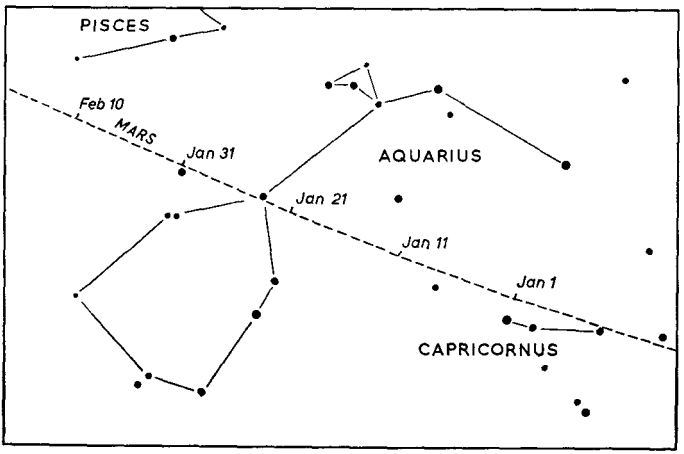
Venus is a morning star, rising about two hours before the Sun at the beginning of the month, but less than an hour before sunrise at the end. The planet is now moving round to the far side of its orbit, and not until the end of the year will it again become a conspicuous object.

Mars moves into Pisces and continues to set in the west in mid-evening. Its rapid motion carries it towards Saturn, which is some



Planetary Orbits in February

degrees to the east, but there is little risk of confusion, as Saturn is much brighter (Saturn magnitude +1·1 to +1·0; Mars +1·4 to +1·5). See also diagram on page 72.



Mars, January–February

Jupiter is at opposition on February 20, due south at midnight, and visible all night. It is a brilliant object (magnitude −2·1) in Leo, moving retrograde towards *Regulus*, and forming a striking configuration with the well-known Sickle of Leo. At opposition the distance of the planet is 409 million miles. The Full Moon of February 14 passes about 3 degrees north of Jupiter, but when the Moon is absent, the movements and phenomena of the four great satellites may readily be observed with quite a small telescope, and well repay study.

Saturn sets in the west in mid-evening, appearing like a first-magnitude star among the faint stars of Pisces. Mars will be seen some degrees to the west, but it moves rapidly up to Saturn by the end of the month (see diagram on page 72).

Jupiter at Opposition. Observers of Jupiter will be anxious to take full advantage of this year's opposition. The Giant Planet is in

Leo, which means that it is still north of the celestial equator, and is excellently placed for study. By next year its altitude will have become less, and for some years following 1970 it will be in the southern part of the Zodiac, so that British and North American observers will be badly handicapped.

The disk is ever-changing, and amateurs continue to do valuable work in taking surface transit observations which may be used to work out the rotation periods of the various belts, zones and special features (such as the Great Red Spot, which remained prominent throughout 1967). In addition to Jupiter itself, attention should be paid to the phenomena of the satellites, since timings of the eclipses, occultations and transits are very useful. The published predictions are sometimes in error by several minutes, so that accurate observations are needed by those mathematicians who compute the orbits.

Of the four Galilean satellites, two (Io and Europa) are roughly the size of our Moon, while the other two (Ganymede and Callisto) are rather larger. Large telescopes will show surface details on them, and there has been some discussion lately as to the size of telescope needed; it has been claimed that moderate instruments will show definite markings, at least on Ganymede. Closer examination, however, shows that this is not possible. Inexperienced observers often make drawings of the satellites showing surface details, but those who have spent many years in planetary work realize that such details are not real. The remaining eight satellites of Jupiter are comparatively small, and no telescopes of amateur size will show them at all; some at least may be captured asteroids rather than genuine satellites.

Leap Year. It is worth noting that 1968 is a leap year, giving February 29 days instead of its customary 28. There is an easy way to check whether a year is a leap year or not; all that need be done is to divide by 4 – if there is no remainder, then February has 29 days. 1968 divided by 4 comes to 492, with no remainder. The only refinement is that with a 'century' year (1800, 1900 etc.) the division is by 400; thus 1900 was not a leap year, but 2000 will be.

The reason for this apparent juggling with the calendar is that the Earth goes round the Sun not in 365 days, but in 365¼. If no adjustments were made, the calendar would steadily become out of step with the seasons, so that after a while Britons and North Americans would be having Christmas in the summer instead of the winter. The present calendar, the Gregorian, is not perfect, but it will take a very long time before any further amendments need be made. The last European country to adopt the Gregorian calendar was Russia, following the overthrow of the Tsars during the First World War.

A Great French Scientist. This month marks the centenary of the death of Jean Bernard Léon Foucault, who died on 11 February 1868. Foucault was born in 1819, and at first intended to study medicine, but soon decided to make a career in physics and astronomy. With his colleague Fizeau, he carried out early experiments in astronomical photography, and as early as 1845 he obtained a clear photograph of the Sun – no easy matter in those days, when photography was in its infancy. However, Foucault's main fame rests upon his experiment carried out in the Panthéon in 1851, when, by means of a long pendulum, he gave a demonstration of the fact that the Earth is rotating on its axis. Many Foucault pendulums have since been set up, and most people will have seen examples of them in scientific museums.

Planets and Stars. This month, both Mars and Saturn are visible in the west in mid-evening, but neither is well placed, and neither is bright. Under such circumstances, it is only too easy for the unwary observer to mistake them for stars – and the usual statement that stars twinkle, while planets do not, is not a safe criterion. Mars, of course, never loses its strong red colour, but Saturn does look very like an ordinary first-magnitude star, though any small telescope will show that it is a definite disk instead of a point of light. Saturn is moving in toward conjunction with the Sun, but will reach opposition again by October; it will then be brighter than at any time during 1967, because its ring-system has begun to open out after the edgewise presentation of late 1966.

March

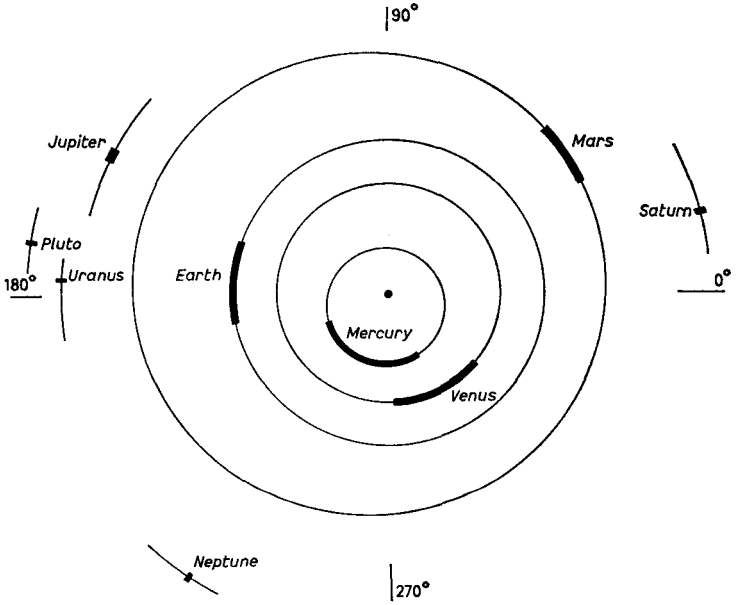
Full Moon: March 14 *New Moon:* March 28

Equinox: March 20

Mercury is at greatest elongation west of the Sun on March 13 (28 degrees) but is very low in the sky at dawn and not likely to be seen.

Venus is still theoretically a morning star but is now too close to the Sun to be seen.

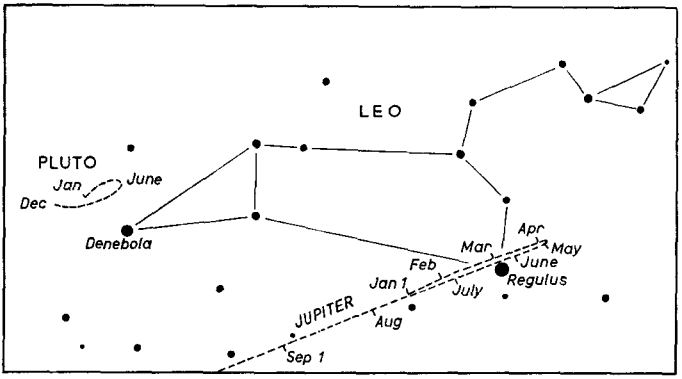
Mars continues to set in the west about two hours after the Sun. It moves from Pisces into Aries during the month, and on March 4 it passes about 2 degrees north of Saturn; the motion of Mars during the month is shown on the Saturn diagram on page 72.



Planetary Orbits in March

Mars should be seen near the thin crescent moon on the evening of March 1.

Jupiter is a brilliant evening star (magnitude −2·1 to −2·0) moving retrograde in Leo. It will be seen close to *Regulus*, and actually passes less than a degree north of this star on the morning of March 5. After reaching its stationary point in April, Jupiter will move forward again, passing *Regulus* once more in June.



Jupiter, January – September

Saturn is now drawing in to the Sun, and is only likely to be seen at the beginning of the month as it sets in the west shortly after sunset. The conjunction of Mars and Saturn on March 4 is referred to in the notes on Mars above.

Uranus is at opposition on March 17 in Virgo; its path during the year is shown in the diagram on page 86. The magnitude of the planet at opposition is +5·7, and it should then be just possible to see it with the naked eye; in a small telescope it appears as a greenish disk. The distance of Uranus at opposition is about 1,609 million miles.

Pluto is also at opposition on March 12 in Leo, and although it is too faint to be seen with small instruments, its position is shown on the diagram on this page. It will be seen that the planet is well

north of the ecliptic. At opposition its distance is 2,900 million miles, magnitude +15.

A partial eclipse of the Sun on March 28–29 will not be visible in northern latitudes (see page 93).

Equinoxes and Solstices. The dates of the equinoxes and solstices are always earlier in leap years than in common years, but the change is really a continuous one. The date of the equinox is not fixed but is defined as the time at which the Sun reaches the First Point of Aries, i.e., when its longitude is 0 degrees. Since the actual period of revolution of the Earth with respect to the equinox is 365·2422 days, the date of the equinox moves forward each year by the odd 0·2422 day (a little less than six hours) and drops back a day in leap years. This applies equally to the other equinox in September and to both solstices, so that all four dates show the same behaviour, advancing by about 6 hours in common years, and falling back by about 18 hours in leap years.

	Equinoxes						*Solstices*					
		d	h		d	h		d	h		d	h
1962	Mar.	21	02	Sept.	23	13	June	21	21	Dec.	22	08
1963		21	08		23	18		22	03		22	14
1964		20	14		23	00		21	09		21	20
1965		20	20		23	06		21	15		22	02
1966		21	02		23	12		21	21		22	07
1967		21	08		23	18		22	02		22	13
1968		20	13		22	23		21	08		21	19
1969		20	19		23	05		21	14		22	00

The dates repeat themselves very closely every four years, but there remains a small error which accumulates. As a result, the dates move slowly backwards throughout the 400-year cycle of the Gregorian calendar, and there is a range of more than two days in the possible dates of each equinox or solstice. In 1968 the dates are earlier than they have been at any time during the present century, but the process will continue, and by the year 2000 the date of the equinox will be March $20^{d}\ 07^{h}$. Since the year 2000 is a

leap year, the dates will continue to move back until 2096, when the equinox will occur on March 19^{d} 14^{h}. In the year 2100, which is not a leap year, the dates will move forward again by one day.

Herschel's Planet. Uranus, at opposition during this month, was the first major planet to be discovered in modern times. It was found in 1781 by William Herschel, then a relatively unknown amateur, but afterwards perhaps the greatest of all astronomical observers.

Five planets (Mercury, Venus, Mars, Jupiter and Saturn) had been known since ancient times. With the Sun and Moon, the total number of bodies in the Solar System was therefore 7; and since 7 was the 'mystical' number, it was tacitly assumed that no more planets could exist. Certainly, Herschel was not deliberately looking for one. He was conducting a systematic review of the sky, using reflecting telescopes of his own construction, when he noticed an object in the constellation Gemini which showed a definite disk, and could therefore not be a star. Naturally, he lost no time in reporting the discovery, but he did not realize that he had found a new planet; his original paper was entitled 'An Account of a Comet'. Not until the movements of the object had been studied, and the orbit worked out, did the full significance of the discovery become known.

Herschel suggested calling his planet the 'Georgium Sidus', in honour of King George III of England and Hanover. (Herschel was Hanoverian by birth, though he had come to England while still a young man and spent the rest of his life there.) The name was not well received, and for a time the planet was called Herschel; but eventually the name Uranus, proposed by the German astronomer, Bode, came into general use.

Uranus is a giant, with a diameter of more than 29,000 miles. Any small telescope will show its disk, but large instruments are needed to bring out any surface detail. The most remarkable feature is the tilt of the axis, which amounts to more than a right angle – so that technically Uranus rotates in a retrograde or 'wrong-way' direction; sometimes the pole appears in the middle

of the disk, while at other times the equator is presented. In constitution, there is every reason to suppose that Uranus is very similar to the larger giants, Jupiter and Saturn, though its greater distance from the Sun means that it must be even colder.

There are 5 satellites. Two (Titania and Oberon) were discovered by Herschel, but Herschel's reported discoveries of extra satellites were not confirmed, and it seems certain that he was misled by faint telescopic stars. The other 2 relatively large satellites, Ariel and Umbriel, were not found until later, while the fifth attendant, Miranda, is excessively faint. None of the satellites can have a diameter as great as 2,000 miles.

Uranus is not a spectacular object, but it is interesting to find, and this is an easy matter. The diagram given on page 86 should enable any observer to locate it almost at once.

The 'Beehive'. March is a good time to look for the open cluster known officially as Præsepe, but nicknamed the Beehive. It lies in the dim Zodiacal constellation of Cancer (the Crab), and may be found by means of the two near-by stars Delta and Gamma Cancri. Præsepe cannot rival the famous Pleiades, but it is easily visible to the naked eye on a moonless night, and binoculars give an excellent view of it; a powerful telescope is not suitable if used at high magnification, since the cluster is rather loose. Apart from the Pleiades and the Hyades, Præsepe is the brightest open cluster visible from European or North American latitudes.

April

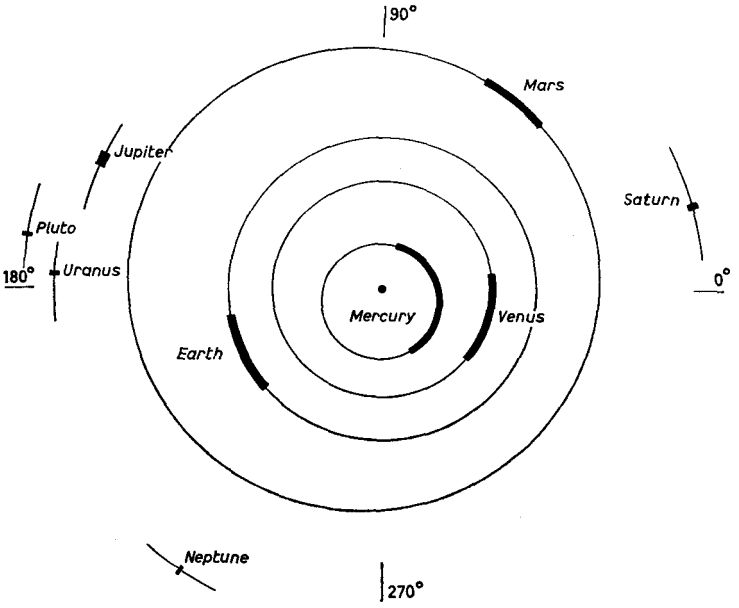
Full Moon: April 13 *New Moon:* April 27

Mercury is at superior conjunction on April 24 and will not be seen during the month.

Venus is still too close to the Sun to be visible.

Mars is moving rapidly eastwards in Aries, but is now drawing close to the Sun. The planet sets about 2 hours after the Sun at the beginning of the month, but will be difficult to see against the bright twilight sky (magnitude +1·6).

Jupiter reaches a stationary point on April 22 a few degrees west of *Regulus*, and then begins to move direct once more. Although less brilliant than it was at opposition (magnitude −1·9 to −1·8)

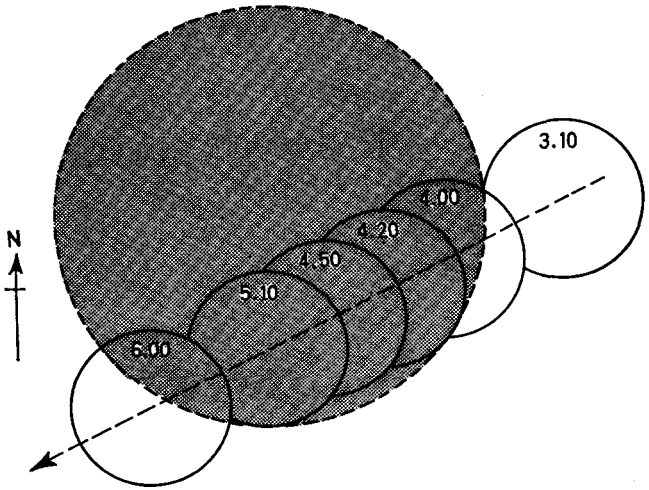


Planetary Orbits in April

it is still a conspicuous object, and may be seen in the south in mid-evening.

Saturn is in conjunction on April 5 and will not be visible during the month.

A total eclipse of the Moon on the morning of April 13 will be visible in Europe and North America. The Earth's shadow will first be seen on eastern edge of the Moon at $3^h\ 10^m$, and the total phase will begin at $4^h\ 23^m$, lasting until $5^h\ 12^m$. In the British Isles (latitude 52 degrees) the Moon will set at $5^h\ 10^m$, just before the ending of the total eclipse (add one hour for British Summer Time). The diagram shows the passage of the Full Moon through the Earth's shadow, and it will be seen that the eclipse is not central. For this reason the duration of totality is only 49^m, whereas under favourable conditions a central lunar eclipse may last for about two hours. A total eclipse of the Moon can be a most impressive spectacle, and as it will be some years before another opportunity such as this occurs in the British Isles, it may well be worth the extra effort of early rising in order to see it.



Eclipse of the Moon, 1968 April 13

Eclipses of the Moon. It cannot be claimed that an eclipse of the Moon has anything like the grandeur of a total eclipse of the Sun. The phenomenon is a gradual one – there is no sudden climax, as with the flashing-out of the solar corona; neither are there any special phenomena to be observed. However, astronomers who pay attention to the Moon's surface will be hard at work on the morning of April 13, provided that the skies are clear.

When the Moon passes into the Earth's shadow, all direct sunlight is cut off. This explains the loss of brilliance; but for the fact that some sunlight is bent on to the Moon by the layer of atmosphere surrounding the Earth, the Moon would vanish altogether. Whether the eclipse is 'bright' or 'dark' depends upon conditions in the Earth's air. The last two total lunar eclipses visible from Europe have been rather 'dark', due to large quantities of volcanic ashes which were sent up from a violent outbreak in the East Indies and remained suspended in the upper air for some months.

Important temperature measures of the lunar surface have been made during eclipses, and it has been established that some local regions, such as that of the magnificent crater Tycho, cool down much less rapidly than their surroundings. Unfortunately, measures of this sort cannot be made with amateur equipment.

It has been suggested that various features show changes during the course of a lunar eclipse, due presumably to the relatively sudden drop in temperature. Of these, the most famous is Linné, on the Mare Serenitatis (Sea of Serenity), about which the published literature is voluminous. Up to 1843, all serious observers drew Linné as a deep, distinct crater, but in 1866 the German astronomer Julius Schmidt announced that the crater of Linné had been replaced by a white patch, in the midst of which was a much smaller craterlet. Schmidt was certain that there had been a radical alteration, but nowadays it is generally agreed that the evidence is very slender, since the observations made before 1866 were too few and made with relatively small telescopes.

Later, it was claimed that during a lunar eclipse, the white patch surrounding the craterlet in Linné increased in size. W. H. Pickering, a famous American observer who died as recently as 1938,

thought that the white patch must be due to hoar-frost, and that new deposits occurred during the wave of cold caused by an eclipse. This view was supported by others, but little faith is placed in it nowadays, and the existence of any hoar-frost is generally discounted. It seems most unlikely that there is any change in Linné as a result of a lunar eclipse; however, systematic observations will certainly be made of it this April 13.

The colours sometimes seen during an eclipse of the Moon are beautiful, though they have nothing to do directly with the Moon itself. They may be seen with the naked eye, but are better observed with binoculars or a telescope. During a 'dark' eclipse, of course, the colours are not so much in evidence, and may be absent altogether.

The Largest Minor Planet. Ceres, at opposition this month, is the largest of the swarm of minor planets or asteroids. Its diameter was once given as 485 miles, but this seems to be an over-estimate, and the modern value is 427 miles. Even so, Ceres is much larger than any of the other asteroids; its nearest rival is Pallas, with only 280 miles.

Yet Ceres is not the brightest of the minor planets, and it can never reach naked-eye visibility. It is outshone by Vesta, partly because Ceres has a lower albedo or reflecting power, and partly because it is farther away; its mean distance from the Sun is 257,000,000 miles, as against 219,300,000 miles for Vesta. In ordinary telescopes it looks exactly like a star, and the only safe way to identify it is to check its star-field over several nights; Ceres will then betray itself by its movement.

Nothing is known about the density of Ceres, but on any logical estimate the escape velocity must be much too low for any atmosphere to be retained. The minor planets are barren, lifeless worlds; many of the smaller members of the swarm are probably not even approximately spherical.

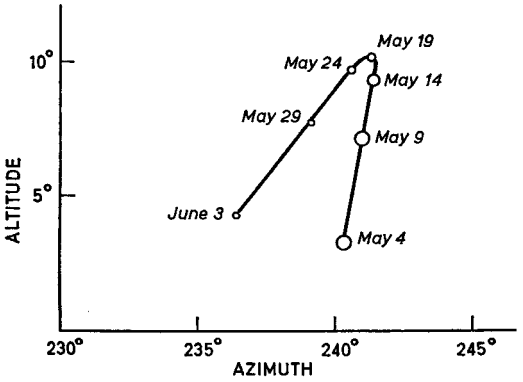
Ceres and the other senior asteroids are confined to the zone between the orbits of Mars and Jupiter. Various smaller objects have eccentric orbits which carry them away from the main swarm,

and some of these may approach the Earth. During 1968 one such body, Icarus, will come within 4,000,000 miles of us, but there is no fear of a collision, as was suggested in some sensational Press reports some months ago. Icarus is only a mile or two in diameter, so that it will never become bright enough to be seen without optical aid. It has a particularly interesting path, since when at its closest to the Sun it approaches within the orbit of Mercury, and must be fiercely heated almost to incandescence.

May

Full Moon: May 12 *New Moon:* May 27

Mercury comes to greatest eastern elongation on May 24 (23 degrees) and conditions are possibly more favourable than they were in January for seeing this planet as an evening star. The diagram shows the changes in altitude and azimuth (see January notes) of Mercury on successive evenings when the Sun is 6 degrees below the horizon; this will be about 40 minutes after sunset at this season. The changes in brightness are roughly indicated by the size of the circles, and it will be seen that Mercury is brightest before the date of elongation.



Mercury, May

Venus is now approaching superior conjunction and is not likely to be seen.

Mars passes into Taurus at the beginning of the month, but is now drawing close to the Sun and is unlikely to be seen in the bright evening sky.

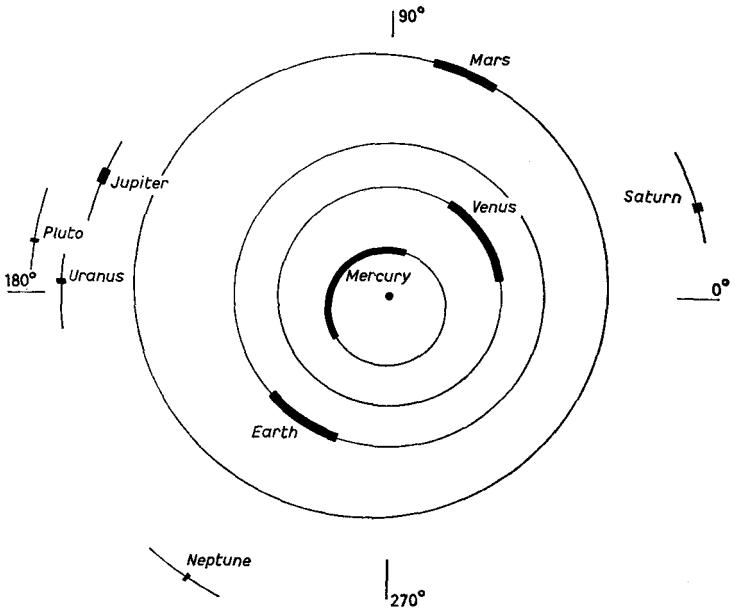
Jupiter is moving direct in Leo, and will be seen in the south soon after sunset, setting in the early morning hours. The planet will

be seen to be some degrees to the west of *Regulus* and its apparent motion towards that star should be quite noticeable.

Saturn is now a morning star and at the end of the month rises in the east in Pisces about 1½ hours before the Sun. It may be difficult to see in the bright dawn sky, since its magnitude is only +0·9.

Neptune is at opposition on May 16 in Libra (see diagram on page 64) and is the only planet in this part of the sky. It is not visible to the naked eye (magnitude +7·7), but in a small telescope it may be seen as a greenish disk. At opposition, the distance of Neptune from the Earth is about 2,726 million miles.

The Surface of Mercury. Mercury should be a naked-eye object for several evenings this month, and is worth looking at, but no small telescope will show surface details there. Mercury is a small world,



Planetary Orbits in May

comparable in size with the Moon, and it never comes much within 50,000,000 miles of us; also, serious observations must be carried out in daylight, since when the planet is visible without optical aid the altitude is inconveniently low.

Various maps have been made, of which the best is that drawn more than thirty years ago by E. M. Antoniadi. Antoniadi, Greek by birth, spent much of his life in France, and made extensive use of the 33 in. refractor at the Observatory of Meudon. He was an expert observer, but nowadays it is thought unlikely that his map of Mercury is more than a rough approximation. Certainly there are light and dark areas, of which the most prominent is the dark patch named by Antoniadi the 'Solitudo Hermæ Trismegisti'; whether or not the surface is mountainous we cannot tell for certain, and neither can we learn whether there are craters similar to those of the Moon and Mars.

Until recently, it was thought that Mercury had a captured rotation, so that its axial rotation period would be equal to its period of revolution round the Sun (88 Earth-days). In this case, part of the surface would experience permanent day, while another part would have everlasting night; because the planet's orbit is not circular, effects analogous to the librations of the Moon would produce a Twilight Zone, between the two extreme regions, over which the Sun would appear to rise and set.

Radar studies, carried out in the United States, have now led to a completely different period of only 58½ days. If confirmed, there will be no day zone, no night zone and no Twilight Zone; every part of Mercury will have sunlight at some time or another. It is too early to claim that the question is definitely settled, but the 58½-day period has been officially accepted, and seems to be founded upon very reliable evidence.

Those who look far ahead, and consider eventual rocket probes to Mercury, have expressed disappointment; after all, a Twilight Zone would have been much the most suitable place to land, since the temperatures would have been less extreme than elsewhere on the surface. Yet whatever may be the rotation period, there seems no chance that life of any sort exists on Mercury. Quite

apart from the high daytime temperature, there is very little atmosphere, and some astronomers doubt whether any atmosphere exists. Antoniadi believed that he had seen frequent 'clouds' over the surface, but this has not been borne out by more modern research.

On the other hand, it seems that too little attention has been paid to Mercury since Antoniadi's time, and it is to be hoped that before long a serious attempt will be made to produce a more reliable map. Unfortunately, it will be necessary to use a very large telescope, preferably a refractor, and this means that the project cannot be undertaken by amateurs.

Capella and Vega. *Capella* and *Vega* are almost exactly equal in magnitude, and lie on opposite sides of the Pole Star, so that they may pass overhead as seen from Britain and the northern United States; *Capella* occupies the place of honour during winter evenings, *Vega* during summer evenings. During evenings in May the two stars are roughly equal in altitude – *Vega* rising, *Capella* sinking – so that it is interesting to compare them. Their colours are very different. *Vega*, an A-type star, is bluish; *Capella* is of spectral type G, and is yellow.

This means, of course, that *Vega* is the hotter of the two. Its surface temperature is more than 10,000 degrees Centigrade, as against less than 6,000 degrees for *Capella*. On the other hand, *Capella* is much the larger, and is more luminous; it is equal to 150 Suns, while *Vega* can match no more than 50 Suns. The distances are, respectively, 47 light-years and 26 light-years. *Capella* is a very close binary.

Though *Capella* and the Sun are very similar in spectral type, there is a great difference between them. *Capella* is a giant, while our Sun is a dwarf of the Main Sequence – as described in the article by Dr Maddison in this *Yearbook*. *Vega*, too, is a Main Sequence star.

The only star in the northern hemisphere of the sky to surpass *Capella* and *Vega* is *Arcturus*, in Boötes (the Herdsman), which also is well seen during the spring. *Arcturus* has a spectrum of type

K, and is a glorious light orange. The most modern magnitude measures give *Arcturus* as —0·06, *Vega* +0·04 and *Capella* +0·05, so that the three are too all intents and purposes equal in brilliance. *Arcturus* is a giant, 100 times as luminous as the Sun and 41 light-years away.

June

Full Moon: June 10 *New Moon:* June 25

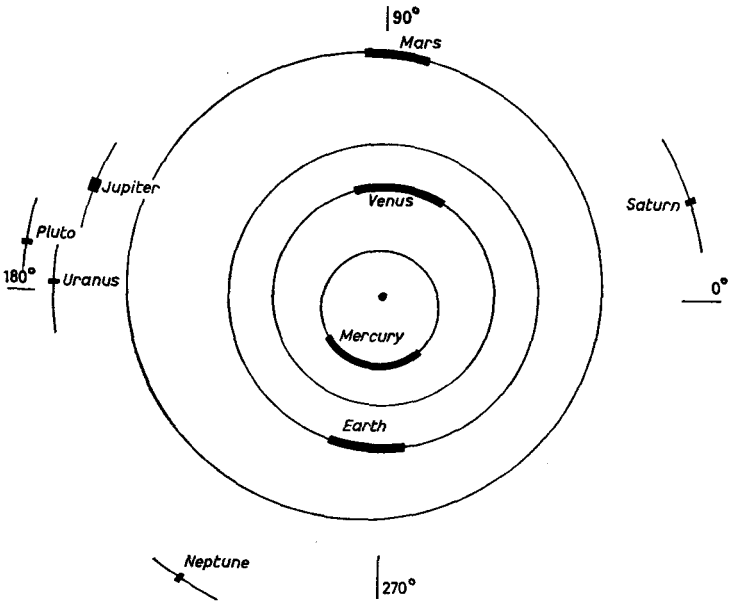
Solstice: June 21

Mercury is in inferior conjunction on June 18 and will not be seen during the month.

Venus is in superior conjunction on June 20 and is not visible.

Mars is now on the far side of its orbit and is in conjunction on June 21; it is not visible during the month.

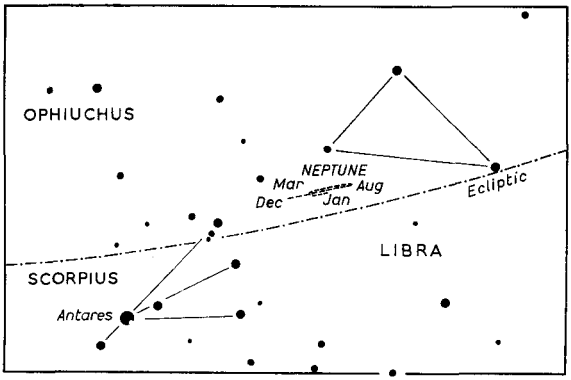
Jupiter is an evening star, moving direct in Leo, and setting at midnight at the beginning of the month. On June 9 it passes less than a degree north of *Regulus* (magnitudes: Jupiter −1·5,



Planetary Orbits in June

Regulus +1·3). This is the third of the conjunctions of the planet with this star, the previous ones taking place on 1967 October 15 and 1968 March 5.

Saturn is a morning star, rising in Pisces at about 1^h in mid-June. It now begins to increase in brightness (magnitude +0·8) but is still to be seen only against the bright twilight sky.



Neptune, January – December

A Lack of Planets. During June, the skies are light in northern latitudes; and this year there is also a notable lack of planets. Mercury, Venus and Mars are out of view; Jupiter is past its best, setting before midnight; Saturn does not rise until the early hours. Therefore, there is a period when no naked-eye planets will be on view. Neptune, which remains in Libra, is visible for most of the brief period of darkness, but it is a most unspectacular object even in large telescopes, and it is of course well south of the celestial equator.

Around the period of Full Moon, there will be no proper darkness at all from the British Isles and the northern United States.

An Astronomical Anniversary. One hundred years ago, on June 29 1868, George Ellery Hale was born in Chicago. As an astronomer, both practical observer and theoretical worker, he has had

few equals; in addition, it was he who was mainly responsible for the building of the great telescopes at Mount Wilson and for the planning of the 200-inch reflector at Palomar.

Hale began his studies when still a boy, and at the age of 23 became famous by his invention of the spectroheliograph. In 1897 he became Director of the Yerkes Observatory, and in 1905 he was transferred to Mount Wilson. He was concerned largely with studies of the Sun, and was responsible for the discovery of magnetic fields in sunspots; but he realized that modern astronomy was in urgent need of a really large telescope, and he was able to raise funds for the erection of first a 60-inch, then a 100-inch reflector at Mount Wilson. The cost was astronomical in every sense of the word, but although Hale could not possibly have financed the projects himself he was able to persuade millionaires to do so. The 100-inch Hooker reflector came into use in 1917, and was responsible for many fundamental advances in astronomy. Until the completion of the Palomar reflector, more than 30 years later, it remained the most powerful telescope in the world. To give just one example: it was with the Hooker reflector that Hubble, in the 1920s, was able to detect Cepheid variables in the Andromeda Spiral, proving that the Spiral itself must be an external system rather than a part of our own Galaxy. No other telescope then built could have been used for this investigation, since no aperture of less than 100 inches would have had sufficient light-grasp.

Still Hale was not satisfied. It is said that his constant call was for 'More light!' and he made up his mind that a 200-inch telescope should be built. Unfortunately, his health had broken down, but he continued in his self-appointed task, and he had the satisfaction of knowing that the 200-inch project was well under way. Hale himself died in 1938; the 200-inch took longer to build than had been expected (due partly to the outbreak of war), but it was finished in 1948, and was appropriately named the Hale Reflector.

No doubt a 200-inch would have been built in time, but without Hale's drive and skill it would have been considerably delayed. Like the 100-inch, it has been responsible for fundamental

advances; indeed, without it, our knowledge of the universe would be much less than is actually the case. Even today, after twenty years, it is still in a class of its own; its nearest rival, the Lick reflector, is 'only' 120 inches in aperture.

The Hale reflector is a triumph of both optics and engineering, and to make anything larger will be a very difficult matter indeed. The Russians have been working upon a reflector of greater size, but so far the 200-inch has no close rival. Moreover, the Earth's atmosphere means that there are definite limitations to the size of telescope which can be usefully employed. Eventually, there is every possibility of our being able to construct telescopes for use either in space or (more probably) on the Moon, where there is no atmosphere to hamper observation; but this lies in the future, and it is too early to make any hard and fast plans.

The immediate need is not for larger telescopes, but for more instruments of the 100-inch to 200-inch aperture range. The Hale reflector is used to its maximum capacity on every clear night, but it cannot possibly cope with the amount of work that is desirable, and in any case it cannot reach the Magellanic Clouds and other vitally important objects of the far southern skies. A 200-inch in, say, Australia or South Africa would be of the utmost value. Parts of South America are also suitable, and before long it is hoped that really large telescopes will be operating from the southern hemisphere.

It was tragic that George Ellery Hale did not live to see the completion of the 200-inch, but at least he will always be remembered – not only for his personal work, but for the work that he made it possible for his successors to carry out.

July

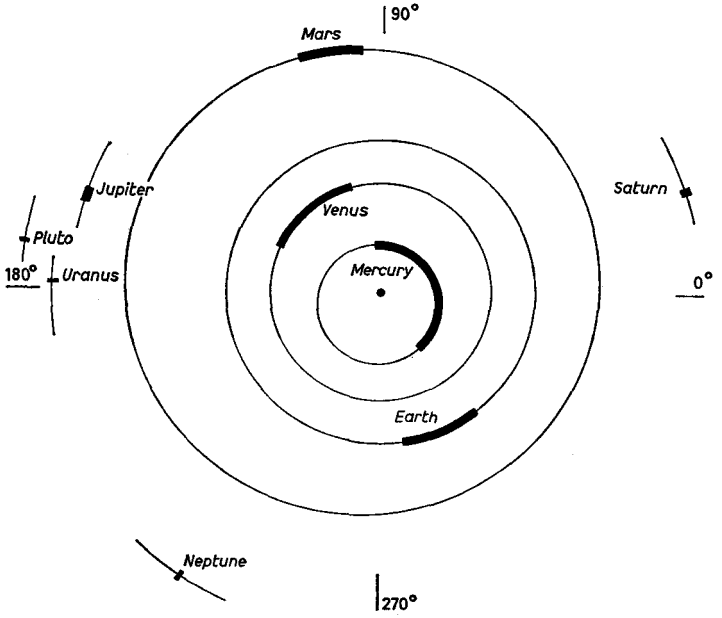
Full Moon: July 10 *New Moon:* July 25

Earth is at aphelion (farthest from the Sun) on July 2, when its distance from the Sun is 94,550,000 miles.

Mercury is at greatest western elongation on July 11 (21 degrees) but the planet will be very low in the north-west at sunrise, and not very bright, so that it will be difficult to see in the bright dawn sky.

Venus now moves east of the Sun and is theoretically an evening star. It sets very shortly after sunset and is not likely to be seen.

Mars begins to appear as a morning star, and at the end of the month it rises about an hour before sunrise in Gemini below the



Planetary Orbits in July

Twins, *Castor* and *Pollux*. Mars reaches its greatest distance from the Earth in mid-July (242 million miles) and it is a faint object (magnitude +1·8) difficult to see in the dawn sky.

Jupiter is still an evening star in Leo, but it now sets in the early evening. The planet is only half as bright (magnitude −1·4 to −1·3) as it was in February, its distance from the Earth being now nearly 600 million miles.

Saturn rises in the east at midnight at the beginning of the month. It is now growing brighter (magnitude +0·8 to +0·7) and although the sky is never really dark at this time of year in these latitudes, Saturn may be recognized easily as it is the brightest object in this part of the sky.

Mars at its Farthest. Mars is now visible once more, in the dawn sky, but it is by no means conspicuous, and is not much brighter than the Pole Star. When at its farthest from us this month, it is more than half as distant as Jupiter was in February; and since Mars is a small planet, only 4,200 miles in diameter, it is naturally unspectacular. Even when at its closest – within 35,000,000 miles, as will be the case at the opposition of 1971 – Mars is still about 150 times as far away as the Moon; and it has been pointed out that ordinary binoculars will show the Moon in as much detail as Mars seen through the world's greatest telescopes. No wonder that the discovery of Martian craters, by the Mariner IV photographs of 1965, came as a surprise to most astronomers.

Eta Aquilæ. One of the most interesting of the summer constellations is Aquila, the Eagle. Its most brilliant star is *Altair*, which is of the first magnitude, and is flanked to either side by two fainter stars, Gamma and Beta Aquilæ. Together with *Vega* in Lyra and *Deneb* in Cygnus, *Altair* makes up the 'summer triangle' which dominates the evening sky in July.

Aquila has a distinctive outline, and it is easy to see why the ancients called it 'the Eagle'. Below *Altair* there is a line of three stars, Delta, Eta and Theta. Of these the central member, Eta

Aquilæ, is a Cepheid variable with a period of 7·2 days and a magnitude range of from 3·7 to 4·5.

Cepheids – so called because the prototype star is Delta Cephei – are of the greatest importance to modern astronomers. They are pulsating, and their variations are absolutely regular, so that their magnitudes for any particular moment may be predicted accurately. What makes them so important is that their periods are linked with their real luminosities; the longer the period, the more luminous the Cepheid. Thus Eta Aquilæ, with its period of over 7 days, is more luminous than Delta Cephei, whose period is only 5⅓ days. Once a Cepheid has been observed, and its period found, its real luminosity can be calculated; this in turn gives its distance, so that Cepheids act as our 'standard candles' in space. They occur in other galaxies as well as our own, and it was by studying the Cepheids in the Andromeda Spiral, more than forty years ago, that Edwin Hubble was able to prove that the Spiral is an external system.

The Cepheid Period-Luminosity Law was discovered by Henrietta Swan Leavitt, who was born at Lancaster, Massachusetts, one hundred years ago – on 4 July 1868. During her career she discovered 2,400 variable stars, 4 novæ and several minor planets, but her great discovery was made in 1912, when she was measuring the short-period variable stars in the Small Magellanic Cloud. To her surprise, she found that the brighter variables had the longer periods. Effectively, all the variables in the Cloud could be regarded as being equally distant from us (just as for all practical purposes, it is accurate enough to say that Hull and Grimsby are the same distance from San Francisco), and so it followed that the longer-period stars really were the more luminous. Later, the same principle was applied to the Cepheids in our own Galaxy, and Miss Leavitt's Law was found to apply to these Cepheids also.

It would be wrong to say that the reason for the Law is properly understood, and there are in fact two distinct types of Cepheids – as well as the RR Lyræ stars, which were once called 'cluster-Cepheids' but are now known to be rather different and to follow a Law of their own. However, the Cepheids have been invaluable

in modern research. Since they are giant stars, they can be seen over great distances.

Apart from Delta Cephei, Eta Aquilæ shows up as the brightest Cepheid visible in northern latitudes. It may be compared with its neighbours, Theta (magnitude 3·1), Delta (3·4) and Iota (4·3); the fluctuations are easy to follow with the naked eye, and it is interesting to draw up a light-curve.

Early Perseids. The Perseid meteor shower reaches its maximum in August, but begins officially on July 27, so that it is worth keeping a watch toward the very end of the month. Moreover, the main spectacle this year will be somewhat spoiled by the Moon, which will be full on August 8 when the shower is expected to be at its best. Photographic enthusiasts may care to attempt some meteor photography; the results can be very spectacular, though luck is the most important factor – one can never tell just when or where a meteor will appear!

In addition to the Perseids and other regular showers, there are the sporadic meteors, which do not belong to any particular shower and which may be seen moving in any direction at any moment. Sporadic meteors are much less common than shower meteors, but they may sometimes be remarkably brilliant – when they are known, rather misleadingly, as fireballs.

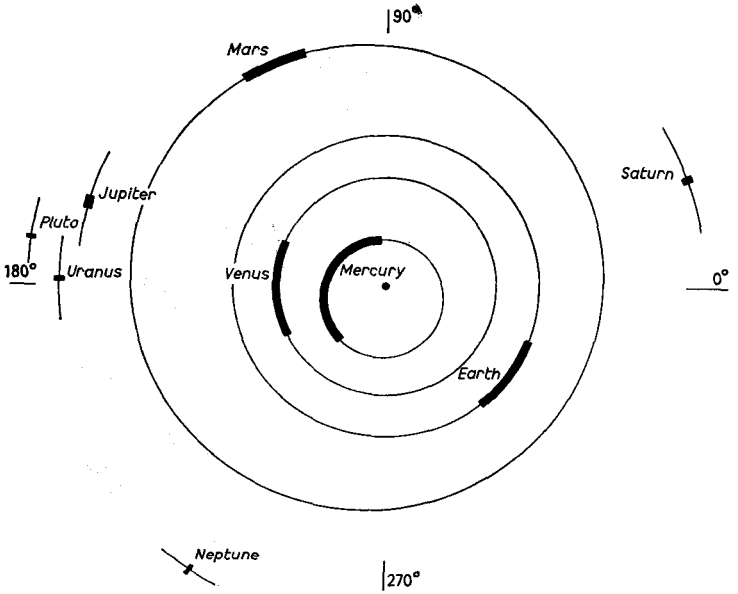
August

Full Moon: August 8 *New Moon:* August 23

Mercury is at superior conjunction on August 7 and is too close to the Sun to be seen.

Venus continues to set about an hour after the Sun. An interesting occultation of Venus occurs on the morning of August 25, but this will call for a good telescope since the event occurs in broad daylight, with the planet only 18 degrees from the Sun. Venus will disappear at the dark limb of the crescent moon (age 1·4 days) at $8^h\ 45^m$ and will reappear at the bright limb at $9^h\ 57^m$.

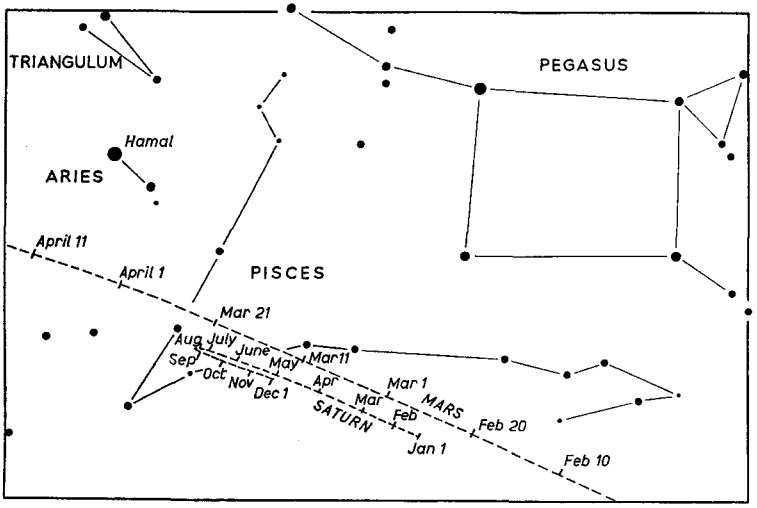
Mars moves direct through Cancer and at the end of the month rises more than two hours before sunrise. Although its distance from the Earth is now decreasing, its eccentric orbit causes its



Planetary Orbits in August

distance from the Sun to increase, and the brightness of the planet therefore decreases (magnitude +1·9 to +2·0) and it will be difficult to see in the dawn sky.

Jupiter is moving towards conjunction and is now only 20 degrees from the Sun, so that it sets shortly after sunset.



Saturn and Mars, January – December

Saturn is at a stationary point on August 8 (see diagram) and rises in the east in mid-evening. It is growing noticeably brighter (magnitude +0·7 to +0·5) and will be visible in a dark sky by midnight.

Sagittarius and the Centre of the Galaxy. During August evenings, the constellation of Sagittarius (the Archer) may be seen low in the south. From London or New York it is never visible to advantage, but from parts of the United States, such as California and Arizona, it is very prominent. It has no distinctive shape, but it contains various bright stars. *Deneb*, *Altair* and Sagittarius lie in almost a direct line, with *Altair* in the middle position; this is probably the easiest way to find Sagittarius. It is in the Zodiac, though during 1968 it contains no planets.

When Bayer allotted Greek letters to the stars in each constellation, in his star maps of 1603, he usually followed the system of making the brightest star Alpha, the second brightest Beta, and so on. His system is convenient, and is still in use. The Greek alphabet is as follows:

α Alpha	ε Epsilon	ι Iota	ν Nu	ρ Rho	φ Phi
β Beta	ζ Zeta	κ Kappa	ξ Xi	σ Sigma	χ Chi
γ Gamma	η Eta	λ Lambda	ο Omicron	τ Tau	ψ Psi
δ Delta	θ Theta	μ Mu	π Pi	υ Upsilon	ω Omega

Perhaps, unfortunately, the strict brightness sequence is not always followed; this in Orion, Beta (*Rigel*) is brighter than Alpha (*Betelgeux*). With Sagittarius, the alphabetical order is chaotic. The brightest stars are Epsilon (magnitude 1·8), Sigma (2·1) and Zeta (2·6), with both Alpha and Beta very much fainter. Incidentally, both Alpha and Beta are too far south to rise in England or the northern United States.

The Milky Way flows through Sagittarius, and is particularly rich. This is natural, since we now know that the star-clouds in Sagittarius indicate the direction of the galactic centre.

The Galaxy is a somewhat flattened system, with a longer diameter of 100,000 light-years; the maximum breadth of the central 'bulge' is about 20,000 light-years. It used to be thought that the Sun lay near the centre, but this is now known not to be the case; the distance between the Sun and the centre of the Galaxy is between 25,000 and 30,000 light-years.

The Milky Way, which appears as a glorious band of light stretching across the sky, is due to a line of sight effect. Any small telescope will show that it is made up of large numbers of faint stars, and the casual onlooker might suppose that these stars almost touch one another; but in reality, the stars in the Milky Way are not in the least crowded. When we look along the main plane of the Galaxy, we see many stars in almost the same direction, and this is the only cause of the Milky Way effect.

Though the Sagittarius star-clouds indicate the direction of the centre, we cannot see through to the centre of the Galaxy itself;

there is too much obscuring material in the way. Fortunately, radio waves are not blocked in the same way as ordinary light, and the new science of radio astronomy, which began with some casual researches by Karl Jansky in the early 1930s, has provided us with considerable information about those regions which we can never see directly.

Everything in the universe seems to be in a state of rotation, and the Galaxy is no exception. The Sun, like the other stars, is moving round the centre, and completes one full journey in over 225,000,000 years – a period which has been aptly, though unofficially, called the cosmic year. One cosmic year ago, the Earth was still in the Age of Amphibians. We cannot hope to speculate as to what will have taken place on our planet by the end of the next cosmic year!

Intruders into the Zodiac. Conventionally, the Zodiac is divided up into the twelve constellations Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio (or Scorpius), Sagittarius, Capricornus, Aquarius and Pisces. Since ancient times the Vernal Equinox has shifted out of Aries into Pisces – and strictly speaking Pisces should now be regarded as the first constellation of the Zodiac instead of the last.

However, there is one notable intruder. This is Ophiuchus (the Serpent-Bearer), a large and rather ill-formed constellation which extends into the Zodiac for some distance between Scorpio and Sagittarius. The Sun, Moon and planets may therefore move into Ophiuchus; and there are other departures, too, from the classic twelve – for instance, for some time during 1967 Saturn lay in Cetus, close to the borders of Cetus and Pisces. Moreover, the remote planet Pluto, whose orbit has an inclination of 17 degrees, can move out of the Zodiac (though it will not do so during the present century).

It is therefore wrong to say that only the twelve famous Zodiacal constellations can be graced with the presence of planets. This fact does not, of course, appear to trouble the astrologers, whose gullibility is equalled only by their ignorance of the fundamentals of true astronomy!

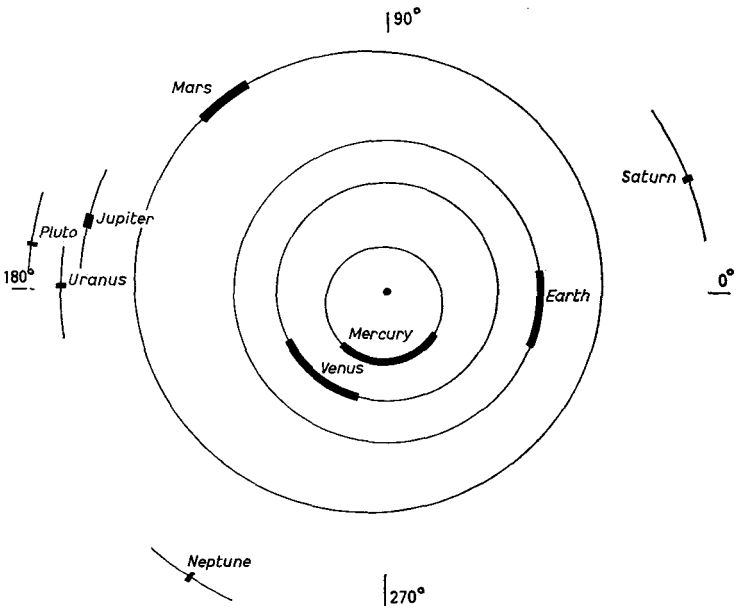
September

Full Moon: September 6 *New Moon:* September 22

Equinox: September 22

Mercury reaches its greatest eastern elongation from the Sun (26 degrees) on September 20, but is then well south of the Sun and very low in the south-west at sunset, setting only a few minutes later.

Venus is now moving out from the Sun, but its position on the ecliptic at this time of year makes it very low in the sky in the south-west (see star chart number 6) and it sets only about 40 minutes after the Sun. It will be interesting to look out for the first glimpse of this planet in the evening sky.



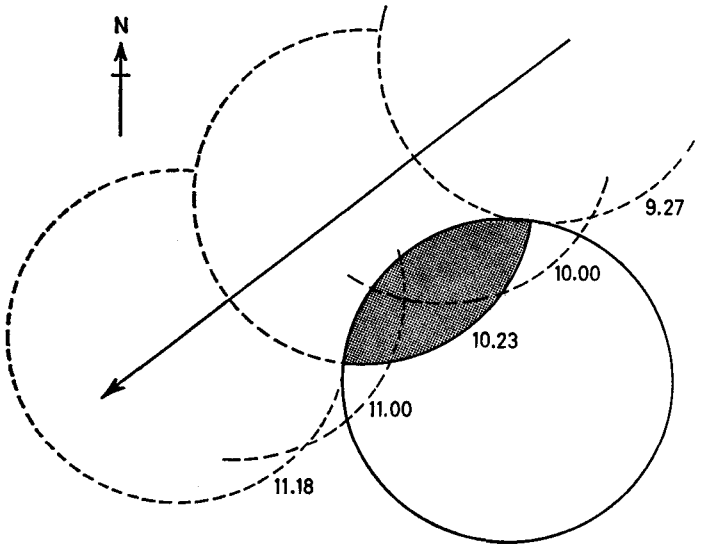
Planetary Orbits in September

Mars is a morning star, and is still a rather faint object (magnitude 2·0), but at the end of the month it may be seen in a dark sky, rising about 3 hours before the Sun. Mars follows along the track of Jupiter in the diagram on page 49 and will overtake that planet in November; it passes less than a degree north of *Regulus* on September 20.

Jupiter is in conjunction on September 9, but it moves rapidly out from the Sun and by the end of the month it may be seen as a morning star (magnitude −1·2), rising about 1½ hours before sunrise.

Saturn is now approaching opposition and rises in the east soon after sunset. It is quite bright (magnitude +0·5 to +0·4) and should easily be recognized, since it is much brighter than any of the faint stars of Pisces shown in the diagram on page 72.

An eclipse of the Sun on September 22 will be visible in the British



Eclipse of the Sun, 22 September 1968

Isles as a partial eclipse (see notes on page 93). The dark body of the Moon will first be seen to enter the upper edge of the Sun at about $9^h\ 30^m$ and will pass off the eastern edge at $11^h\ 19^m$ (add one hour for British Summer Time). At mid-eclipse at about $10^h\ 30^m$ the Moon will obscure 30 per cent of the diameter of the Sun. The diagram shows the passage of the dark body of the New Moon across the upper edge of the Sun, as seen from south-east England; the times will, in general, be a few minutes earlier for places north and west of Greenwich.

This Month's Eclipse of the Sun. It is unfortunate that the total phase of this solar eclipse will be seen only from parts of Siberia. There are no really 'accessible' total eclipses for the next few years so far as Britons are concerned, though Americans will be able to see one from Mexico on 1970 March 7, and the eclipse of 1972 July 10 will be total from parts of Japan, Canada and the Atlantic. So far as Britain is concerned, the next opportunity will not be until 1999 August 11, when the track will cross Cornwall.

However, the partial phase this month will be well worth observing. It will be obvious enough with the naked eye, but a telescope will naturally show it to much better advantage.

A word of warning should be given here. The Sun is an intensely brilliant object; after all, its surface temperature is 6,000 degrees Centigrade. To stare at it for long periods is to court disaster. For viewing the eclipse with the naked eye, a very thick piece of smoked glass, or something equivalent, should be used – and it is unwise to stare for more than a few seconds even with this protection. During the last large partial eclipses visible from Britain, quite a number of people who ignored this warning had to be treated in hospital for eye-injuries.

The danger is even worse if binoculars or telescopes are used, and anyone foolish enough to look straight at the Sun in this way will certainly be permanently blinded. This is not mere alarmism; it has happened all too often. As soon as the Sun's light and heat are focused on to the eye, tragedy is inevitable.

Unfortunately, it is possible to buy special sun-caps, made of

dark filters, which are designed to be placed over the telescope eyepiece so as to cut down the light and heat and make it safe to look direct. *These sun-caps are not safe.* They cannot afford full protection, and moreover they may at any time splinter or crack – in which case the luckless observer may not have enough time to remove his eye from the danger-zone.

The only sensible way to observe the Sun, whether eclipsed or not, is by projection. The method is to point the telescope at the Sun, taking care to keep one's eye well away from the eyepiece, and then project the solar image on to a white card or screen placed behind the eyepiece. If this is done, the Sun will be well shown, together with any sunspots which may be present. This is also the proper way to look at this month's partial eclipse. It will be interesting to make regular drawings, so as to follow the Moon's passage across the bright solar disk.

An early eclipse observer was Joseph Nicolas De L'Isle, who was born in Paris in 1688, and died there two hundred years ago, on September 12, 1768. It was the eclipse of 1706 which attracted De L'Isle to astronomy, and after graduating he spent more than twenty years in Russia as 'Court Astronomer', finally returning to his native France in 1747 to become a professor of astronomy in Paris. One of his pupils was Messier, the great comet-hunter who is best remembered nowadays for his catalogue of star-clusters and nebulæ.

Delphinus. One of the most prominent of the small constellations is Delphinus, the Dolphin, which lies roughly between *Altair* and the Square of Pegasus. It has no star brighter than Beta, of magnitude 3·7, but it is a beautifully compact little group, and is quite unmistakable. According to an old legend, it represents the dolphin which rescued the famous singer, Arion, who had been thrown into the sea by a party of sailors who were anxious to lay hands upon his riches. The dolphin brought Arion safely to shore, and was rewarded by being placed in the sky!

One of the stars in Delphinus, Gamma, is double; the components are of magnitudes 4·5 and 5·5, and more than 10 seconds

of arc apart. The primary is yellow, the companion greenish. Gamma Delphini is a beautiful object in a moderate telescope.

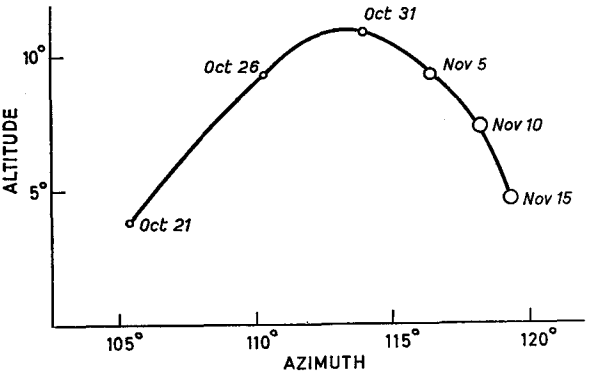
Delphinus is not the only small constellation in the region, but the others – Equuleus (the Little Horse), Sagitta (the Arrow) and Vulpecula (the Fox) are much less conspicuous. Vulpecula does however include the Dumb-bell Nebula (Messier 27), which is a fine example of a planetary nebula – too faint to be well seen in small telescopes, but showing considerable detail when photographed with large instruments.

On July 8, 1967, the well-known British amateur astronomer G. E. D. Alcock, of Peterborough, discovered a nova in Delphinus. At its brightest it was of magnitude $5\frac{1}{2}$, and so was visible to the naked eye even though it did not become conspicuous; it has now, of course, faded well below naked-eye visibility. The discovery cannot be attributed to pure chance, since Alcock had for some years been carrying out systematic surveys in a search for novæ; the instrument used was a pair of good binoculars. Previously, he had discovered no less than four comets, so that his observational record is impressive indeed. His work stresses yet again the fact that skilful amateurs can make important contributions to astronomical science.

October

Full Moon: October 6 *New Moon:* October 21

Mercury is at inferior conjunction on October 15, but moves out to greatest western elongation (19 degrees) on October 31. This is a favourable opportunity to see this planet as a morning star. The diagram shows the changes in altitude and azimuth of Mercury on successive mornings when the Sun is 6 degrees below the horizon – about 35 minutes before sunrise at this time of year. The changes in brightness are roughly indicated by the sizes of the circles; it will be seen that Mercury is much brighter after the date of western elongation.



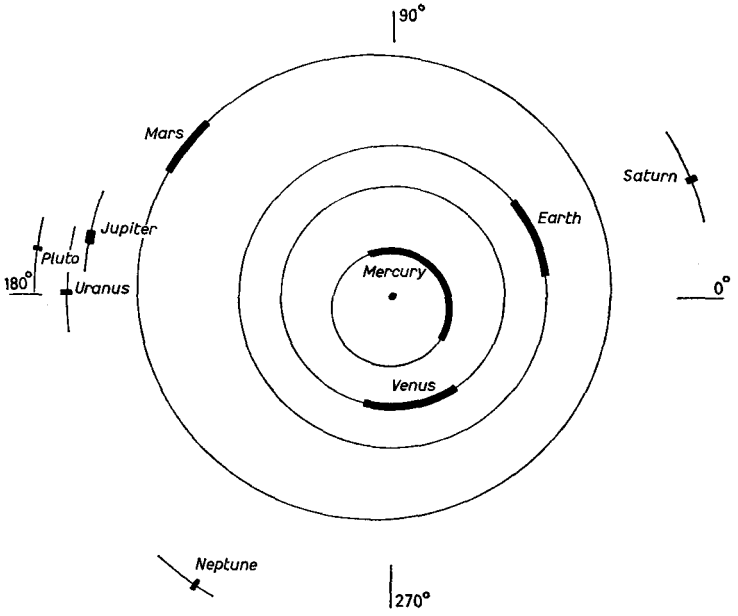
Mercury, October – November

Venus is an evening star, but is still very low in the south-west. By the end of the month it is more than 30 degrees east of the Sun and it becomes more easily visible, remaining in the sky for more than an hour after sunset

Mars is a morning star in Leo, rising about 4 hours before the Sun, but is still only of the second magnitude. At the end of the month it passes from Leo into Virgo, and remains in that constellation for the rest of the year.

Jupiter is also a morning star, rising two or three hours before sunrise. The planet passes from Leo into Virgo in mid-October, and begins to grow a little brighter (magnitude −1·2 to −1·3).

Saturn is at opposition on October 15, and is therefore visible all night. The planet is much brighter (magnitude +0·3) than it was



Planetary Orbits in October

at the 1967 opposition owing to the fact that the rings are now more widely open. The distance of Saturn from the Earth at opposition is about 875 million miles. A small telescope will show something of the splendour of Saturn's rings, as well as the largest satellite Titan.

A total eclipse of the Moon occurs at midday on October 6, but is visible only on the other side of the Earth (see note on page 93).

Janus. Late in 1966, the French astronomer Audouin Dollfus announced the discovery of a new satellite of Saturn, now named Janus. It moves round Saturn at a distance of only about 98,000 miles, so that its orbit lies within that of the quondam closest satellite, Mimas.

Janus was detected in 1966 because the ring-system was then more or less 'closed', and was difficult to see even with large telescopes. By 1967 the rings had started to open out again, and during 1968 they will be even better displayed; Saturn will resume its usual glory, and will again be probably the most beautiful object in the sky, but the faint inner satellites will be harder to see, and Janus, in particular, will be very elusive. Its diameter cannot be much more than 100 miles.

Pegasus and Andromeda. The southern aspect during autumn is dominated by Pegasus, the Flying Horse. Candour compels one to admit that the group is most un-equine; its main stars make up the famous Square, which cannot be mistaken even though the individual stars are not above the second magnitude.

Three of the stars in the Square are Alpha, Beta and Gamma Pegasi. The fourth, rather surprisingly, is included in the adjacent constellation, Andromeda, as Alpha Andromedæ; its proper name is Alpheratz. Originally it was included in Pegasus, as Delta Pegasi, and this is certainly more logical, since it is an essential part of the distinctive pattern.

Alpheratz is not unique in having been 'transferred' in this way. Gamma Scorpii, of magnitude 3·3, is now included in Libra, and known as Sigma Libræ. The reason for this change is obscure – though it may perhaps be admitted that Libra is very deficient in stars of even modest brightness, whereas Scorpio has plenty to spare! The third case is that of the star once known as Gamma Aurigæ, but now officially called Beta Tauri. The magnitude is 1·6, so that the star is bright enough to be really prominent. Its proper name is Al Nath.

Proper Names of Stars. There are many stars which have individual names, mainly of Arabic origin. Indeed, there are some stars which

have more than one name; Eta Ursæ Majoris, in the tail of the Great Bear, is either Alkaid or Benetnasch. Moreover, some star-names may be spelled in various different ways. Alpha Orionis, the famous red supergiant, has a name which may be spelled Betelgeux, Betelgeuse, Betelgeuze or Betelgueux; there are also several permissible pronunciations, though many people prefer to call it 'Beetle-juice'.

The modern tendency is to ignore the proper names of all stars below the first magnitude, apart from Polaris and a few other special cases. The first-magnitude stars were described in an article in the 1966 *Yearbook*, and their names were given. It may be worth adding a list of the proper names of stars below the first magnitude which are still sometimes used. There are, of course, many others; but few people will want to remember that, for instance, Pi Cygni is known as Azelfafage and Gamma Ceti as Alkaffaljidhina! Names of stars below the first magnitude which are not totally obsolete are:

Alpha Andromedæ	Alpheratz
Alpha Arietis	Hamal
Beta Aurigæ	Menkarlina
Alpha Canum Venaticorum	Cor Caroli
Beta Canis Majoris	Mirzam
Epsilon Canis Majoris	Adara
Alpha Cassiopeiæ	Shedir
Alpha Cephei	Alderamin
Beta Ceti	Diphda
Beta Cygni	Albireo
Alpha Draconis	Thuban
Theta Eridani	Acamar
Gamma Geminorum	Alhena
Alpha Gruis	Alnair
Alpha Herculis	Rasalgethi
Alpha Hydræ	Alphard
Beta Leonis	Denebola
Gamma Leonis	Algieba
Alpha Ophiuchi	Rasalhague
Gamma Orionis	Bellatrix
Delta Orionis	Mintaka
Epsilon Orionis	Alnilam

Zeta Orionis	Alnitak
Kappa Orionis	Saiph
Beta Pegasi	Scheat
Epsilon Pegasi	Enif
Alpha Persei	Mirphak
Epsilon Sagittarii	Kaus Australis
Sigma Sagittarii	Nunki
Beta Tauri	Alnath
Eta Tauri	Alcyone
Alpha Ursæ Majoris	Dubhe
Beta Ursæ Majoris	Merak
Gamma Ursæ Majoris	Phad (or Phekda)
Delta Ursæ Majoris	Megrez
Epsilon Ursæ Majoris	Alioth
Eta Ursæ Majoris	Alkaid

The only stars below the first magnitude whose proper names are nearly always used are: Alpha Germinorum (Castor), Alpha Ursæ Minoris (Polaris), Beta Persei (Algol), Omicron Ceti (Mira) and Zeta Ursæ Majoris (Mizar).

Oddly enough, a few of the first magnitude stars have no 'official' proper names; such as Alpha Centauri, the brightest star in the sky apart from Sirius and Canopus. Air navigators call it Rigel Kent, but astronomers still refer to it simply as Alpha Centauri.

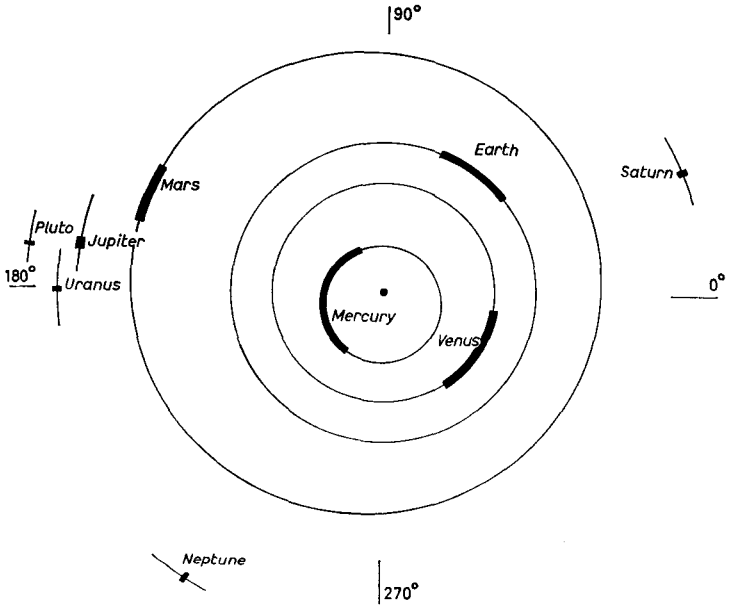
November

Full Moon: November 5 *New Moon:* November 20

Mercury may be seen in the south-east at dawn during the first few days of the month (see notes for October) but then moves in towards superior conjunction and will be too close to the Sun to be seen.

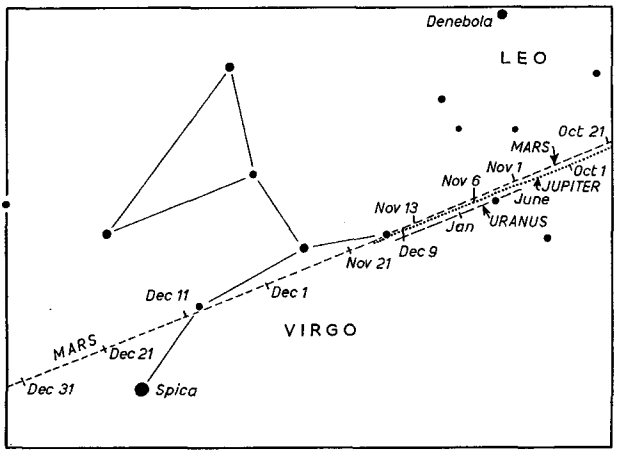
Venus now moves rapidly out from the Sun, and is a bright evening star setting in the south-west more than 2 hours after sunset at the end of November. The planet is growing brighter (magnitude −3·5 to −3·6) as its distance from the Earth decreases.

Mars is a morning star, moving direct in Virgo. The planet is at aphelion (greatest distance from the Sun, 155 million miles) on November 12. Its reduced distance from the Earth (and later in



Planetary Orbits in November

the month its distance from the Sun) now begin to take effect, and the planet grows brighter (magnitude +1·9 to +1·8). Mars is in the same neighbourhood as Jupiter and Uranus, and its rapid motion in passing these planets is shown in the diagram. Mars passes about a third of a degree north of Jupiter on November 6, and less than a degree north of Uranus on November 13. All three planets are occulted by the Moon on November 16, but this event takes place in daylight hours.



Mars, Jupiter and Uranus, November

Jupiter rises in the early hours of the morning in Virgo, and is now growing brighter (magnitude −1·3 to −1·5). It may be seen very close to Mars on the morning of November 6; Jupiter will then be south of Mars, but about twenty times as bright.

Saturn is visible for most of the night, but sets in the west before dawn; at the end of the month it will be seen in the south in mid-evening. The brightness of the planet begins to decrease (magnitude +0·4 to +0·6) as its distance from the earth increases.

The Leonids. Interest in the Leonids was first aroused by the impressive shower of 1833, when shooting stars were seen to fall

like snowflakes from the head of Leo. It now seems that the display of 1966 November 17 was even more spectacular, although observations were confined to the western United States, and nothing was seen of it in Great Britain. Observers in Arizona, California, Texas and New Mexico have all reported exceptional activity, and this time many photographs have been obtained as records of this surprising event. At Kitt Peak, Arizona, at an altitude of 6,850 feet, a team of observers watched the shower as it built up. The meteors were too numerous to count, but estimates are in agreement and show that the rate was more than a thousand a minute by $11^h\ 30^m$, and rose rapidly to a peak of about 40 per second – more than 140,000 per hour – just before 12^h (these times are G.M.T.; this is just before dawn in Arizona). The maximum was sharply defined, and the rate fell away rather more slowly after the peak. All parts of the sky were streaked with these shooting stars, most of which were very bright, and the position of the radiant, from which they all appeared to come, was very obvious.

It was at the 1833 display that the presence of this radiant was first realized. Intense interest in meteors was prevalent at this period, for it had only recently been established that meteors were visitors from outer space. Elaborate calculations proved that this shower recurred every 33 years; it had been seen in South America by Humboldt in 1799, and was traced back in historical records to the year 902. It was later shown that the meteoric dust travelled in an orbit similar to that of Tempel's comet of 1866, in which year there was another fine display. Yet another great shower was confidently predicted for 1899, but this failed to take place, and this disappointment certainly led to a decline in the interest in meteoric astronomy. The failure of the 1899 shower to materialize has, in fact, been described as the worst blow ever suffered by astronomy in the eyes of the public – a slight exaggeration, perhaps, but it certainly taught us a lesson!

During the present century the Leonids have shown no great activity; in fact there has been, if anything, a decline in the rates expected. There was some increase in the numbers of Leonids in 1965, but although some further increase was expected in 1966,

nobody anticipated the spectacular display that actually occurred. One fact of great interest was the recovery of the parent comet, last seen in 1866. This comet (now called Tempel-Tuttle) was shown to be identical with the comet of 1366, and on this basis new calculations were made, and an observation of a comet in 1699 was found to agree, thus strengthening the figures for the orbit. A new prediction was made, and the comet was recovered at the end of June in 1965 at the Boyden Station in South Africa, the recovery being confirmed by plates taken at Mount Palomar. This comet has a large eccentric orbit with a period of 33 years, and at aphelion it moves out beyond the orbit of Uranus. The orbit is inclined to the ecliptic at about 17 degrees, but the meteoric dust travels in the retrograde direction, so that it meets the earth almost head-on. For this reason the Leonids are very swift, the combined speeds of earth and dust being about 45 miles per second. The radiant, in the head of Leo, lies only about 10 degrees from the point in the sky towards which the earth is travelling at the time. This point, which bears the rather archaic title of 'the Apex of the Earth's Way' is roughly 90 degrees from the Sun, and a little thought will show that it can never rise in the east until after midnight. This is why we always see more meteors after midnight than before it.

The failure of the Leonids to appear for nearly a hundred years has been attributed to the perturbation of the meteor stream by the major planets, but if this is the case (and it has not yet been put to the test of the lengthy calculations which would be required) the disturbance must now have been reversed, bringing the stream back once more into an orbit which the earth will intersect. Perhaps computers of the future will be able to make a more definite prediction for 1999.

The Distances of the Planets. This month Mars, Jupiter and Uranus are all in Virgo, and seem as though they are close together. Of course, this is certainly not the case. It is only too easy to forget the vast scale of the Solar System, and it should be noted that the distance between Uranus and the Sun is more than three times as

great as that between Jupiter and the Sun. Therefore, Uranus is considerably further from Jupiter than we are.

Consider the outermost giants, Uranus and Neptune. Their mean distances from the Sun are respectively 1,783,000,000 miles and 2,793,000,000 miles. The orbit of Neptune lies more than a thousand million miles beyond that of Uranus – and a space-probe bound for Neptune would not have completed very much more than half its journey when it crossed the orbit of Uranus.

Pluto, usually the outermost planet, has a relatively eccentric orbit; its distance from the Sun ranges between 4,566,000,000 miles at aphelion to only 2,766,000,000 miles at perihelion. Since the perihelion distance of Neptune is 2,769,000,000 miles, Pluto can approach us more closely than Neptune is able to do; but there is no danger of a collision between Neptune and Pluto, because Pluto's orbit is inclined at an angle of 17 degrees. Pluto is now approaching the Sun, and will reach perihelion in 1989. When it is near aphelion, early in the 22nd century, it will be excessively faint – and incidentally it will then be so far south in the sky that it will never rise in the latitude of London.

December

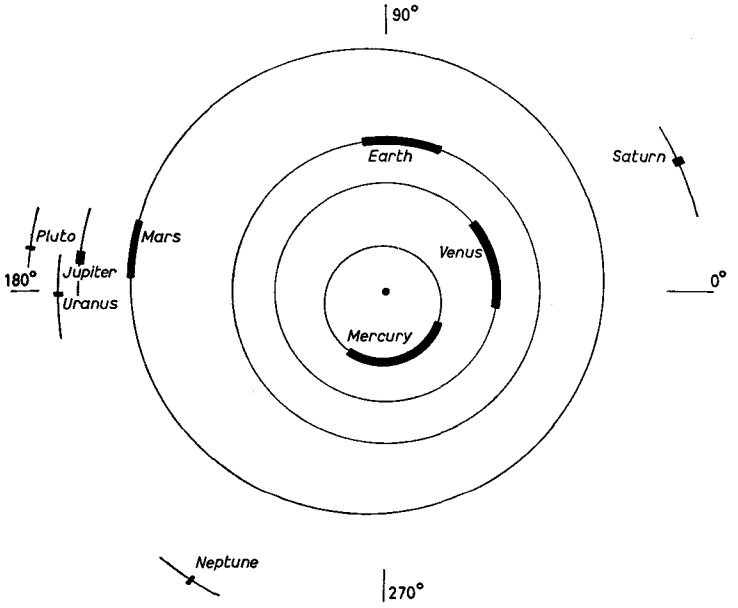
Full Moon: December 4 *New Moon:* December 19

Solstice: December 21

Mercury is at superior conjunction on December 7 and is not visible during the month.

Venus is now more readily visible (magnitude −3·6 to −3·8) in the south-west at sunset, and at the end of the year sets nearly four hours after the Sun. It will be at its greatest eastern elongation in 1969 January, and will be a brilliant evening star throughout the spring months.

Mars is a morning star, rising in Virgo at about 2^h at the end of the year. The planet passes about 4 degrees north of *Spica* on Decem-



Planetary Orbits in December

ber 16 (magnitudes: Mars +1·6, *Spica* +1·2). The next opposition of Mars occurs in 1969 at the end of May, when the planet will be in Scorpio, at a distance of 45 million miles.

Jupiter is a brilliant morning star (magnitude −1·5 to −1·7) in Virgo, rising at midnight at the end of the month. Jupiter passes about half a degree north of Uranus on December 9 (see diagram on page 86). The next opposition of Jupiter takes place in 1969 March.

Saturn reaches a stationary point in Pisces on December 22, and will be seen in the south as soon as it is dark, setting just after midnight at the end of the month. The planet is now half a magnitude fainter than it was at opposition in October. The next opposition of Saturn occurs in 1969 October, by which time it will have moved into the next constellation, Aries.

Gaseous Nebulæ. Of all the constellations in the sky, one of the most splendid – perhaps the most magnificent of all – is Orion. With its distinctive shape and its numerous brilliant stars, it cannot be mistaken.

One feature of great interest is the gaseous nebula in the Hunter's Sword, known commonly as M.42 because it was the 42nd entry in Messier's catalogue published in 1781. It is distinctly visible to the naked eye as a misty patch, and binoculars show it excellently; with a telescope, it is a superb sight. There is dark nebulosity as well as bright, and there is the so-called Trapezium, the multiple star Theta Orionis.

A gaseous nebula shines because of the radiation emitted by the stars which are contained in it. With M.42, the stars are extremely hot, so that they excite the atoms in the gas and make the nebula self-luminous; if the stars are less hot, as with the Pleiades, the nebula will shine only by reflection, and will be much less evident.

The Orion Nebula is very extensive – and photographs taken with large telescopes show that much of the constellation is involved in nebulosity. However, the gas is very rarefied, and is much less dense than the Earth's atmosphere. It is thought that gaseous

nebulæ are stellar birthplaces, and there is excellent evidence that fresh stars are being produced from the gas in the Sword of Orion.

Messier's catalogue included nebulous objects of all sorts. As well as gaseous nebulæ, there were star clusters such as the Pleiades, Hyades and Præsepe; globular clusters, of which the best example is M.13 in Hercules; a few planetaries, notably the Ring, M.57 Lyræ, and the Dumb-bell, M.27 in Vulpecula; and, of course, galaxies such as M.31, the Andromeda Spiral. At that time it was not known that galaxies and gaseous nebulæ are entirely different in nature, and in any case Messier made no attempt to sort his objects into definite classes. He was not particularly interested in nebulæ, and merely wanted to have a list of them so that he could avoid wasting time during his comet-hunts.

Venus as an Evening Star. Venus is now a splendid object in the west after sunset. It will be visible on Christmas Night, weather permitting, and astronomers will – as usual! – be asked whether Venus can have been the Star of Bethlehem. The answer is, baldly: no. Venus has been known since very early times, and its appearance can have caused no comment. If the Star of Bethlehem story is founded on fact, then the object must have been exceptional, and certainly nothing so commonplace as a familiar planet.

A December Centenary. This month's anniversary is of the birth of José Comas Solá, one of the leading Spanish astronomers of modern times. Comas Solá was born at Barcelona on 1868 December 19, and spent most of his life there; he became Director of the Barcelona Observatory in 1903. He paid great attention to Saturn, and also discovered two comets, one of which is periodical; he spent many nights in searching for new minor planets, and discovered eleven. He died on December 2, 1937.

Eclipses, 1968

In 1968 there are four eclipses, two of the Sun and two of the Moon.

1. *A partial eclipse of the Sun* on March 28–29, visible in the South Pacific Ocean and parts of Antarctica and South America. At maximum eclipse about nine-tenths of the Sun will be obscured.

2. *A total eclipse of the Moon,* on April 13, visible in Europe, the Atlantic Ocean and America. The Moon enters the Earth's shadow at $3^h\ 10^m$, and total eclipse begins at $4^h\ 23^m$ and will last until $5^h\ 13^m$. In the British Isles the Moon will set before the end of totality.

3. *A total eclipse of the Sun* on September 22 will be visible throughout most of Europe and Asia as a partial eclipse (the track of totality lies entirely in western Siberia). In the British Isles the eclipse begins at about $9^h\ 30^m$ and ends at $11^h\ 19^m$, in the south-east, but a few minutes earlier in more westerly regions. At mid-eclipse at $10^h\ 30^m$ about 30 per cent of the Sun's diameter will be covered by the Moon.

4. *A total eclipse of the Moon* occurs at midday on October 6 and will be visible only in Australasia and America.

Occultations

In the course of its journey round the sky each month, the Moon passes in front of all the stars in its path, and the timing of these occultations is useful in fixing the position and motion of the Moon. The Moon's orbit is tilted at more than 5 degrees to the ecliptic, but it is not fixed in space. It twists steadily westwards at a rate of about 20 degrees a year, a complete revolution taking 18·6 years, during which time all the stars that lie within about $6\frac{1}{2}$ degrees of the ecliptic will be occulted. The occultations of any

one star continue month after month until the Moon's path has twisted away from the star, but only a few of these occultations will be visible at any one place in hours of darkness.

There are only four first-magnitude stars that can be occulted by the Moon; these are *Regulus*, *Aldebaran*, *Spica* and *Antares*. In 1968 occultations of *Antares* continue throughout the year, only one of these being visible in the British Isles on January 25 in daylight hours. A series of occultations of *Spica* commences in July, while the planets Mercury, Venus, Mars, Jupiter and Saturn are all occulted at some time and place; of these only the daylight occultation of Venus on August 25 will be visible in the British Isles.

Details of occultations of the planets, and of all stars down to magnitude 7·5, as well as possible occultations of stars by planets, are published in the annual *Handbook* of the British Astronomical Association. Similar information applicable to North America is given in the monthly journal *Sky and Telescope*.

Comets in 1968

The appearance of a bright comet is a rare event which can never be predicted in advance, because this class of object travels round the sun in an enormous orbit with a period which may well be many thousands of years. There are therefore no records of the previous appearances of these bodies, and we are unable to follow their wanderings through space. The comets of short period, on the other hand, return at regular intervals, and attract a good deal of attention. Unfortunately they are all faint objects, and are recovered and followed by photographic methods, using large telescopes. Most of these short-period comets travel in orbits which carry them out to the orbit of Jupiter, and it is this planet which is responsible for the severe perturbations which many of these comets undergo.

Three of these short-period comets, which had been regarded as lost, were recovered in 1964–5 as a result of more precise calculations and the use of large telescopes. *Comet Holmes* was last

seen in 1906, and *Comet de Vico-Swift* in 1894; both of these will be disturbed by Jupiter in 1968, the approach of *de Vico-Swift* being a close one, leading to a considerable increase in the size of the orbit. The third of these newly recovered comets is *Tempel-Tuttle*, last seen in 1866. This is the parent comet of the great Leonid meteor stream, and it is significant that in 1966 a magnificent display of these meteors was seen in the south-western United States. This comet has a period of 33 years, and its orbit stretches out beyond that of Uranus. (See also page 88).

In 1968 the following short-period comets are expected to return to perihelion:

Comet Schwassmann-Wachmann (2), first discovered in 1929, has made six observed appearances in all. It has an orbit which lies entirely outside that of Mars, with a small eccentricity and small inclination to the ecliptic; its period is about $6\frac{1}{2}$ years.

Comet Schaumasse has made six observed appearances, the first being in 1911. This comet has a larger and more eccentric orbit, with a period of about 8 years and an inclination of 12 degrees. The perihelion lies just outside the Earth's orbit.

Comet Perrine-Mrkos was first seen in 1896 and again in 1909. It was not seen at subsequent returns, and was actually abandoned as lost, but was recovered by chance by Mrkos in 1955. It has a period of $6\frac{1}{2}$ years and an inclination of 16 degrees.

Comet Schwassmann-Wachmann (1) is visible every year because it travels round the Sun in a nearly circular orbit lying entirely between the orbits of Jupiter and Saturn. It has a period of 16 years, and is remarkable because it undergoes changes of brightness, which seem to have some connexion with solar activity.

Meteors

Meteors ('shooting stars') may be seen on any clear moonless night, but on certain nights of the year their number increases noticeably. This occurs when the Earth chances to intersect the orbit of a meteor swarm, which is a concentration of meteoric dust moving in an orbit around the Sun. Such an intersection can occur

only at one particular time of year, but if the dust is spread out along the orbit, the resulting shower of meteors may last for several days. The word 'shower' must not be misinterpreted – only on very rare occasions have the meteors fallen so fast as to resemble snowflakes falling.

The naked-eye study of meteors is quite a laborious task, but even a casual observer, watching for, say, ten minutes on an August night, may observe a number of Perseids. If their tracks are marked on a star map, and traced backwards, a number of them will be found to intersect in a point (or a small area of the sky) which marks the radiant of the shower. This gives the direction from which the meteors have come.

The following table gives some of the more easily observed showers, with their radiants; the effect of moonlight in 1968 is indicated.

Limiting dates	*Shower*	*Maximum*	*R.A.*	*Dec.*	*Notes*
Jan. 3–4	Quadrantids	Jan. 3	$15^h\,28^m$	$+50°$	
April 20–22	Lyrids	April 22	$18^h\,04^m$	$+33°$	
July 27–Aug. 17	Perseids	Aug. 12	$3^h\,04^m$	$+58°$	M
Oct. 15–25	Orionids	Oct. 20–21	$6^h\,24^m$	$+15°$	
Oct. 26–Nov. 16	Taurids	Nov. 1–7	$3^h\,36^m$	$+14°$	M
Nov. 15–17	Leonids	Nov. 16	$10^h\,08^m$	$+22°$	
Dec. 9–14	Geminids	Dec. 13	$7^h\,28^m$	$+32°$	
Dec. 20–22	Ursids	Dec. 22	$14^h\,28^m$	$+76°$	

M = moonlight interferes

Minor Planets in 1968

Nearly 2,000 minor planets are listed in the catalogues, but of these only the 'big four', Ceres, Pallas, Juno and Vesta, can reach any considerable brightness, and only the last of these, Vesta, can occasionally be seen with the naked eye. In 1968 Vesta does not quite reach the sixth magnitude; at opposition on October 20 it is

only of magnitude 6·4. Ceres, at opposition on April 19, magnitude 6·6, and Pallas, magnitude 6·9 on March 13, are fainter still, while Juno, whose orbit is rather more eccentric than the others, will only reach tenth magnitude in April.

Some Events of 1969

ECLIPSES

In 1969 there will be two eclipses of the Sun; there will also be three penumbral eclipses of the Moon.

March 18 – an annular eclipse of the Sun, visible in Antarctica, Australasia and parts of Eastern Asia.

September 11 – an annular eclipse of the Sun, visible in America and Siberia.

The penumbral eclipses of the Moon occur on April 2, August 27 and September 25.

THE PLANETS

Mercury may best be seen as an evening star at eastern elongation on May 5, and as a morning star at the time of western elongation on October 14.

Venus will be at greatest elongation on January 26, and will be a brilliant evening star in the early months of the year. After inferior conjunction on April 8 it will be a morning star, reaching greatest western elongation on June 17.

Mars will be at opposition in Scorpio on May 31.

Jupiter will be at opposition in Virgo on March 21 and in conjunction on October 9.

Saturn will be in conjunction on April 18 and is at opposition in Aries on October 29.

Uranus will be at opposition on March 22 in Virgo.

Neptune comes to opposition on May 18 in Libra.

Pluto is at opposition on March 14 in Leo.

Occultations of *Antares* and *Spica* continue throughout the year, and a series of occultations of *Regulus* will begin in December.

PART TWO

Article Section

The Article Section continues on the lines of those in previous *Yearbooks*, and it is hoped that there will be 'something for everybody'. The first contribution has been written for complete beginners, who are anxious to make some sort of a telescope at the minimum possible cost; W. M. Baxter's article about the Sun is in the nature of a general introduction. Both our lunar contributions are more specialized, and this applies also to the two articles upon meteoritics. All three stellar articles are non-technical without being too elementary. Last year's edition contained an article by Dr E. M. Lindsay of Armagh; this year we are delighted to be able to include a contribution from Professor P. A. Wayman, Director of the other famous Irish observatory.

Taking our contributors in the order in which their articles are printed (instruments and Solar System subjects first, by the usual convention!) we have:

T. J. C. A. Moseley. Amateur astronomer who lives in Armagh, Northern Ireland. He specializes in observations of Jupiter, but also pays attention to the Moon, Saturn and Mars.

W. M. Baxter. Director of the Solar Section of the British Astronomical Association. His sunspot photographs are known all over the world, and he has also written extensively; among his works is a book, *The Sun and the Amateur Astronomer*, published in 1963.

Miss Barbara Middlehurst. Astronomer at the University of Arizona, Lunar and Planetary Laboratory (Tucson). In addition to her mathematical work and her editing of many important books published from the Lunar and Planetary Laboratory, Miss Middlehurst has paid great attention to the Moon, and has carried out pioneer work into studies of 'lunar events'.

Professor S. Miyamoto. Director of the Kwasan Observatory, University of Kyoto, Japan. In addition to astrophysical work, Professor Miyamoto is an international authority on lunar matters, and has made extensive contributions in this field. He also pays great attention to the planet Mars.

H. G. Miles. Lecturer at the Lanchester College of Technology, Coventry; and Director of the Artificial Satellite Section of the British Astronomical Association. He undertook the official researches into the Barwell Meteorite fall, and spent a vast amount of time in collecting information and in interviewing witnesses.

Dr G. J. H. McCall. Reader in Geology, University of Western Australia; and Honorary Associate, Western Australian Museum, Perth. Dr McCall is a specialist in vulcanology, and has published many original research papers. In astronomy, his main interests are in the Moon and in meteoritics.

Dr R. C. Maddison. Lecturer at the University of Keele, in Staffordshire, and in charge of the Observatory there. He is a physicist with a particular interest in astronomy, and is undertaking researches into devices such as image converters. He lectures extensively outside as well as in the University, and also appears on television.

Iain Nicolson. University of St Andrews, Scotland. He is particularly interested in problems of interstellar material, and is undertaking researches into the whole problem.

Professor P. A. Wayman. Director of the Dunsink Observatory, Republic of Ireland. Professor Wayman was formerly at the Royal Greenwich Observatory, Herstmonceux, before taking up his Directorship at Dunsink, where he is continuing his original researches in astrophysics and stellar astronomy.

Dr G. N. Katterfeld. President of the Commission of Planetology, U.S.S.R. Academy of Sciences. Dr Katterfeld carries out his researches at the Department of Geomorphology, Leningrad State University, and is recognized as a leading world authority in this field.

A Simple Home-made Refractor

T. J. C. A. MOSELEY

In astronomy the enthusiastic beginner is often put off by the prohibitive cost of a telescope – £40 or £50 is a minimum price for a useful instrument, though second-hand ones can of course be obtained more cheaply if one is persistent and patient enough to find one. However, it is not as difficult as might be thought to make a serviceable instrument oneself, for an almost negligible expenditure. Anyone reasonably good with their hands can attempt a medium-sized reflector, but for the younger reader, or those who have not got the necessary facilities, a small refractor is quite easy to make; and though one will hardly discover a comet, or contribute much to our knowledge of Mars, it will certainly repay what little trouble one put into it, and will also whet one's appetite for a larger instrument, as well as providing useful experience in this field.

There are two main types of telescopes; the refractor, which uses a convex lens to collect light from the object one is studying and to form it into an image; and the reflector, which uses a mirror to do the same thing. Light, however, as Newton discovered, is made up of different colours, as one can see in a rainbow, which is simply sunlight (ordinary white light) broken up into its constituent colours. A lens bends the light from the object one is studying to form an image of the object at its focus, but because of the inherent properties of light it bends or 'refracts' (hence the name refractor) the different colours by different amounts; the shorter wavelengths, i.e. violet, are bent more than the longer, i.e. red. This means that not all the light will be brought to focus at the same point; one cannot therefore get a sharp focus, and the image will have a fringe of false colour round it. This can

be almost completely cured by making the lens of two different types of glass whose refracting properties tend to cancel each other out, but such a 'compound' lens is beyond the capabilities of all but the skilled optician, and is accordingly very expensive. A reflector does not suffer from this trouble, as a mirror reflects all colours equally, and if one wants a fairly powerful instrument a reflector is the only alternative.

One might well ask, 'Why not a small reflector instead of a small refractor?' The answer to this is that aperture for aperture (i.e. the diameter of the mirror or lens), a refractor is more powerful than a reflector: a four-inch reflector (telescopes are described in terms of their aperture in inches) is the minimum useful size, while a four-inch refractor is an instrument with which useful work can be done. Also, a reflector is considerably more troublesome to make, as it involves grinding one's own mirror. However, if one is prepared to put up with the false colour, which is not a serious handicap for our purposes, a small refractor will give quite pleasing views of the Moon's craters and mountains, sunspots, the phases of Venus, the four bright moons of Jupiter and the famous rings of Saturn; it will show nebulæ and galaxies down to the ninth magnitude, as well as some beautiful star-clusters and double-stars. Like all astronomical telescopes it gives an inverted image, so it cannot really be used on terrestrial objects.

A simple refractor has only three parts: the main objective or object-glass, which collects the light; the eyepiece, which magnifies the image formed by the objective; and a tube to hold these two together.

The larger the objective we use the better, since this will enable us to collect more light and therefore see fainter objects. Also, since the magnification is limited, in theory, only by the amount of light present in the image, it will allow us to use a higher magnification. But if one uses too high a magnification the image will be too faint for any detail to be seen.

Simple 'non-achromatic' lenses are rarely made more than 3 inches in diameter and even these are fairly expensive. Therefore an objective of $1\frac{1}{2}$ inches to $2\frac{1}{2}$ inches diameter is probably better.

The lens that is chosen should have as long a focal length (the distance from the lens to its focus) as possible, for two reasons. Firstly, a lens of relatively long focal length does not suffer as much from false colour as one of short focal length; and secondly, although the eyepiece does the actual magnification, the longer the focal length of the objective the greater the magnification obtained with any one eyepiece. (The magnification depends on the ratio between the focal length of the objective and the focal length of the eyepiece, e.g.; if the objective has a focal length of 40 inches and the eyepiece 1 inch, the magnification is $\times 40$, if the focal length of the eyepiece is $\frac{1}{2}$ inch the magnification will be $\times 80$.)

In choosing a lens for a telescope two factors must be borne in mind. The first is that objectives with a long focal length have a very small field of view and this makes it difficult to find the object one is looking for in the telescope. The second is that there is a maximum useable magnification for any objective. Even in a perfect telescope about 80 magnifications ($\times 80$) per inch of aperture is as much as can ever be used, while $\times 50$ to the inch is a normal upper limit. With the rather imperfect optics of a simple refractor, $\times 30$ per inch is about as much as can be used profitably. This limits the eyepiece power that can be used with any objective. For example, if a $2\frac{1}{2}$-inch objective of focal length 60 inches is obtained there is no point in getting an eyepiece lens of shorter focus than $\frac{3}{4}$ inch, which will give an overall magnification of $\times 80$, i.e. $\times 32$ per inch.

In some earlier books on the subject it was stated that suitable O.G. lenses could be obtained in the form of spectacle lenses; but this is no longer possible, as these lenses are now rarely circular, and more important, due to a new Ministry of Health regulation they are curved in a special way to conform to the curvature of the eye, and are thus not suitable.

Where then does one obtain a lens? If one can find a magnifying glass of unusually long focal length, say 8 inches or more, this can be used. As it has a relatively short focal length it will have a large field of view, and will give impressive views of the Milky Way; it will be good for finding and tracking artificial

satellites – a field where the amateur can do useful work; but magnifications of more than ×10 are impractical, and it will not compare with even medium power binoculars, though it is of course incomparably cheaper. False colour will be rather obtrusive in a lens of such short focal length, but this can be considerably reduced by stopping down the aperture with a cardboard ring about one-sixth of an inch wide, which will only reduce the aperture by one-third of an inch.

A lens of the required focal length will usually have to be bought; either from one of the large optical manufacturers, who usually sell these non-achromatic lenses at from 10*s* to 25*s* depending on size; or from your local optician (your spectacle supplier), who can order one if he has not got exactly what you want. I obtained a very satisfactory 2-inch diameter lens of 52-inch focal length in this way for 10*s* 6*d*.

I would recommend a lens of 2 inches or 2½ inches diameter as these are not really much more expensive than smaller ones and have a better light grasp; while a lens of 3 inches diameter or more could easily cost pounds and would have to have a very long focal length to avoid false colour. The focal length should be at least 15 times the diameter of the objective, while 20 is better; the ratio between the focal length and diameter of a lens is known as the F-Ratio. My 2-inch lens is F26 but this makes the telescope almost 5 feet long; anything longer is impractical since it is difficult to obtain a suitable tube and the telescope becomes awkward to handle. For a 2½-inch objective, F20 is probably the most that can be used, though if a rigid tube of the right length is available F25 would be worth considering; with a 1½-inch objective anything up to F30 is possible. Since our simple telescope will not bear an eyepiece much shorter in focus than ¾-inch, a long focus objective is a necessity if we want a useful magnification.

A suitable eyepiece is probably the most difficult item to obtain, though not necessarily the most expensive. A simple convex lens of short focal length – about 1 inch is the shortest that can be used with this type – can be used, but will not give very good results; a jeweller's eyepiece is better, but best of all is a microscope eye-

piece; both these latter can be picked up quite cheaply in a second-hand junk shop, or perhaps careful searching of an attic or loft will reveal something. Of course, if a proper telescope eyepiece can be obtained cheaply, so much the better, but it is not worth spending much more than 10*s* on this item unless you are sure that the objective is worthy of it.

Having obtained an objective and eyepiece, we must now arrange them in a tube so that the eyepiece will be at a distance from the objective equal to the sum of their focal lengths, making sure that their optical axes are coincident, i.e. they are squared on.

If the focal length of the objective is less than about 40 inches, a cardboard tube of suitable length and diameter may be found. It does not matter if the tube is an inch or so too wide, as the objective can be fitted into a holder or 'cell' which in turn can be made to fit the tube, but it should be remembered that, thickness of cardboard being the same, a narrow tube is stronger than a wide one. If the tube is only just too short it does not matter, as the eyepiece holder can be made long enough to make up for this.

However, if the focal length is fairly long, one may have to join two or more tubes together, though this is bound to make the tube rather too flexible. If the tubes will fit tightly inside each other, so much the better; if not, the smaller will have to be chocked up with tightly rolled brown paper, or other 'hard' paper, or cardboard, until it will fit tightly into the larger: sellotape provides a tough outer cover, and is so thin that with careful experimenting a very good fit can be obtained. The more the inner tube is fitted inside the larger, the less the join will flex (if the tube is bent, only part of the light collected by the objective will find its way into the eyepiece, and the image will suffer accordingly); but it must be remembered that if the inner tube is too narrow, or is pushed too far into the outer, it will obstruct part of the cone of light formed by the objective, and the image will be dimmed. An alternative arrangement is to get two tubes of the same size and join them by wrapping paper or card tightly round them as far on either side of the join as possible. The whole of the inside of the

tube should be painted black to avoid reflections, which cause optical 'ghosts'.

Tubes can be obtained from stationers or furnishers, while postal tubes are quite good, if rather on the short side. If one cannot obtain a suitable tube, quite a good substitute can be made from large sheets of brown paper tightly rolled round an object of suitable diameter – a shovel handle will usually suffice. It is a good idea to glue the inner roll in position before completely removing the tube from whatever one has wound it round, or the roll will start to unwind inwards and one has to start again; failing this, something should be inserted to stop any unwinding until one is ready to put in the objective. It is perhaps better to be on the safe side and not finally seal up the tube until one has both objective and eyepiece in position, as it is often found that final adjustments will have to be made; elastic bands will hold everything until one is ready to finally fix the parts together.

A word of warning! It is courting disaster, and a flagrant neglect of Spode's Law (which states that if things can go wrong – they will, and is nowhere more evident than in astronomy!) to make the tube before one actually has the objective, as one is lucky if the focal length is within several inches of what one asked for, and the tube may be too short. It is quite easy to measure the focal length. Simply hold the lens up so that a sharp focus of the Sun is obtained on a white card or similar surface; the focal length is then the distance from the lens to this focus. On no account should the Sun be viewed, even for a fraction of a second, through either the lens or the complete telescope, as the eye will be badly damaged by the heat, and permanent blindness is quite possible.

It is not a good idea to fix the objective directly into the main tube, as this means that one can only handle it from one end, and any adjustments will involve the whole tube. It is better to make a cell for the lens about 6 inches long, which will fit inside the main tube and can be easily removed for adjustment and cleaning, and the aligning will be both easier and more stable. To make a cell, all that is required is some fairly stout cardboard and some glue. Roll a piece of card into a tube exactly the same size as the lens –

two complete turns are enough, but more can be used if it is to be built up to fit the inside of the telescope tube. The tube should be about 6 inches long. Put the objective in the middle of the tube, and square it on as nearly as possible, keeping the tube rolled with elastic bands – do not glue it yet. Next, take more card and make two tubes, each about 3 inches long, so that they will be a fairly tight sliding fit in the main tube. Stiff card should be used for this, and only one complete roll given to each. It is very important that the ends of these tubes are exactly at right-angles to their lengths. Fit one tube on each side of the objective in the large tube, tapping each gently until their ends fit against the lens all round its edge. Keeping them like this, one can now roll the large tube as tight as it will go without straining it, and it may be glued just enough to keep it together. If this has been done correctly, when the lens in its now completed cell is put into the tube it should be properly aligned, i.e. the focus should be exactly in the centre of the tube.

If the cell is now pushed several inches farther into the end of the tube than its final position, the focus should be near the other end of the tube, and if a piece of semi-transparent paper is put over the eye-end of the tube, and the telescope pointed at the Sun (without looking directly up the tube), it can be seen whether the focus is in the centre; if not, the objective should be tilted very slightly towards the eye end, on the side of the tube that the focus was nearest to; and by trial and error the objective can thus be finely adjusted in its cell.

If the tube is long enough, the objective should be placed about 2–3 inches in from the end of the tube; this protects it, and will also help to stop it from dewing on cold nights; if the tube is not long enough another piece of card rolled into a tube about 6 inches long will do for a dewcap, and will probably be needed anyway.

One is now ready to fit in the eyepiece. If it is just a simple lens, a cell will have to be made for it, in the same way as for the objective, but if it is a proper eyepiece, all that is needed is to fit it into a tube, 10–15 inches long, which will just slide in the main tube; this enables one to focus fairly accurately. If the main tube

is too long to allow a focus to be achieved the remedy is obvious, but do not cut anything until one has tried it on an astronomical object – the Moon is ideal, but any bright star will do, as the focus for this will be shorter than for the nearest steeple! One should allow at least 3 inches depth of focus, as different eyepieces vary in their focal length.

When one has tried the telescope on several types of objects in the sky, say the Moon, bright stars, planets, star clusters such as the Pleiades and nebulæ such as the Orion Nebula, one will have a fair idea of whether the telescope is as well adjusted as possible; one can then tighten everything up, remembering that the objective and the eyepiece will have to be removed from time to time for cleaning.

In trying the telescope, one will have noticed how difficult it is to keep the telescope on the object one is looking at; obviously even this type of instrument needs a stand of some sort.

A simple altazimuth stand (like a camera tripod), which allows up and down, and side to side, movement, will suffice. It does not matter how makeshift it is, as long as it allows free movement and is fairly steady. The actual mount can be supported on a tripod made from old brush handles and the like, stuck into holes bored in a wooden disk about 2 inches thick, and 8 inches diameter, which can be obtained at any sawmill or timber-merchant for a shilling or so. The height of the tripod should not exceed about two and a half times the spread of the legs. In the centre of the disk bore a hole which will just take another piece of round wood about 1½ inches diameter, which will form the vertical axis of the mount. Another smaller disk of wood can be fitted round this, two or three inches from one end, to rotate on top of the tripod disk. The length of the vertical axis depends on two opposing factors: the longer it is, the less stable it will be; and the shorter it is, the lower the upper limit to which the telescope can be raised. It is a matter of the lesser of two evils; if the attention is to be concentrated on the Solar System, one will not need an altitude of more than 60 degrees; if one is interested in stellar objects a greater height will be required. There is not much point in making it more than

15 inches or so, as beyond this it takes a large increase in height to give an appreciable increase in observable altitude.

Having decided on the height of the vertical axis, we must now arrange for motion in altitude (up and down). This can be done by cutting down about 3 inches of the top of the vertical axis to a

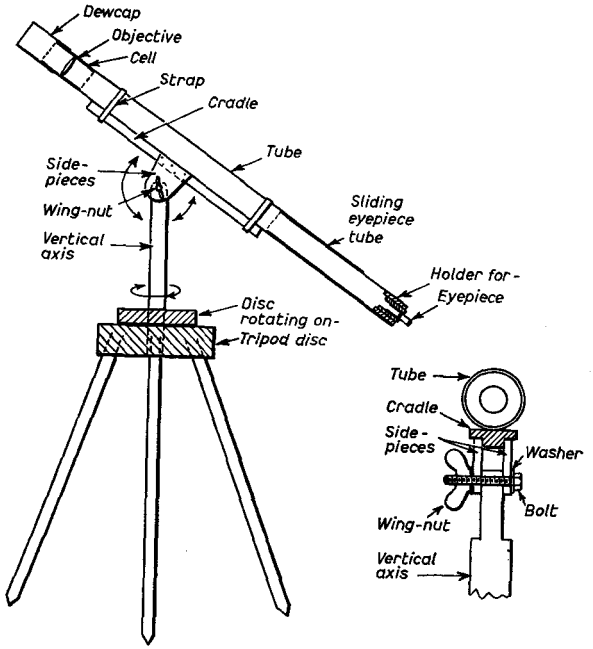


Fig. 1. Telescope on Altazimuth stand

parallel-sided form, and through the centre of this, about 1 inch from the top, bore a hole to take a $2\frac{1}{2}$ inch or 3 inch by $\frac{1}{4}$ inch bolt and wing nut (or something similar). The telescope itself is mounted on a cradle, which can be simply a piece of wood long enough to support about two-thirds of the tube, to which the telescope can be strapped. The cradle has to be fixed so that it will rotate freely but firmly about the horizontal axis, i.e. the bolt at the top of the vertical axis. This can be done by nailing on to the side of the cradle

two 'ears' or sidepieces of wood, to fit closely outside the flattened top of the vertical axis, with holes bored through each side to take the bolt: by tightening the wing nut, using washers if necessary, one can achieve the right degree of friction for the telescope to stay in position, while moving freely when desired (see Fig. 1).

Of course, the above design is not the only one, perhaps not even the best, but it shows the general principles involved: all one needs is a sturdy tripod, and a mount capable of smooth motion in two directions.

A more advanced type of mount is the Equatorial, which is simply an altazimuth with its vertical axis tilted to point at the North Pole; simple motion from east to west is then enough to keep a celestial object in the field of view. If one's telescope gives very good results, this type of mount would be worth consideration (details can be found elsewhere) but otherwise it is not worth the trouble.

Anyone with a little practical ability can make an instrument such as is described above; most people with a fair idea of what is required could probably make something better, but even if one has only the basic form given here, endless pleasure can be obtained if one is enthusiastic enough to exploit it to the full, and the patient observer can make himself useful in various fields, such as artificial satellites and variable stars, without any more sophisticated equipment than this little home-made refractor.

The Sun

W. M. BAXTER

Hints on observing the Sun were given in the 1963 *Yearbook of Astronomy* for the guidance of amateur astronomers. The present article is not intended for the serious observer, but rather for those taking a first interest in astronomy and who may be inclined to neglect our nearest star in their keenness to study the night sky. It is hoped that a general note on the Sun will be of interest, perhaps as a stepping-stone to serious daytime observing.

First let us remind ourselves of a few facts relating to the Sun as an astronomical body. When we compare the brilliance of the midday Sun with the feeble light of the stars in the night sky, seen as only tiny points of light even in our most powerful telescopes, it is difficult to appreciate that the Sun is just a star. Light travels at a speed of 186,000 miles per second, and takes only $8\frac{1}{2}$ minutes to reach us from the Sun, whereas the light from the next nearest star takes $4\frac{1}{3}$ years. Light from distant galaxies can be on its journey for thousands of millions of years before it reaches our telescopes from the far regions of space.

It will be understood, therefore, that astronomers and astrophysicists make a very close study of the Sun, not only for itself but because they are thus able to examine a star at very close quarters; obtaining a 'close-up' view of a typical star a mere 93 million miles away.

Some stars are larger than our Sun, some are smaller, some hotter, some cooler, and the Sun can be considered as being an 'average' star, but it is *the* star that really matters to us as it is the source of all life and power (apart from nuclear energy) on our Earth and our food and clothing; all originate from the solar radiations. We depend on the Sun for our light and heat, and for

our seasons; if the Earth were a planet further from the Sun it would be too cold to support life as we know it, while if we were nearer, the heat would make life equally impossible. We are at just the right distance for life to have developed in the way it has over the millions of years that the Earth has existed.

The Sun is an extremely hot 'ball of gas' (mainly hydrogen) 864,000 miles in diameter or over one hundred times the diameter of the Earth. The temperature at its surface can be measured as being about 6,000°C, while at its centre it is estimated to be in the region of fifteen million degrees. The Sun has been pouring out energy into space in vast quantities for millions of years, and we see no reason why this should not continue for many more millions of years – fortunately for us. Undoubtedly the energy is being continually maintained by atomic processes in the Sun's interior, rather like millions of thermonuclear bombs continuously turning hydrogen into helium with an excess in the form of vast quantities of energy.

The whole body is in a turbulent condition, and sometimes the 'storms' on the Sun are made manifest to us by the outbreak of sunspots on its surface indicating powerful magnetic forces at work underneath (see Plate 1). The cause of sunspots is not fully understood, although there are several theories.

Solar activity varies in a strange, but very regular, way over a cycle of about eleven years. Some years show intense activity with many sunspots visible on any day, sometimes large enough to be seen with the naked eye (through a dark filter) but they decrease in number and in size as the cycle proceeds until some six years after 'maximum' sunspot activity, when days, and weeks, go by without any signs on the Sun's surface. Then the tide turns and the spots appear again, to reach the next 'maximum' five years or so after 'minimum'. Another strange fact is that spots commence appearing at the higher latitudes, north and south, and approach the equator as the cycle proceeds. New cycle spots appear as the old cycle spots are dying out in the low latitudes. Spots are never seen at the poles and rarely on the equator. These changes in latitudes are another unexplained feature of the solar activity.

The last 'maximum' occurred at the end of 1957, when the Sun was very active indeed and, in anticipation of this, the International Geophysical Year (IGY) was fixed accordingly, to study the radiations we receive on the Earth, particularly at the poles. The Arctic is not a convenient place for observations, being a floating ice cap; but the Antarctic was, and still is, a base for numerous scientific experiments by large expeditions from many countries. The more recent studies there have been to record the activities of the 'quiet' Sun during the period of sunspot 'minimum', so that the information obtained during the International Year of the Quiet Sun (IQSY) could be compared with the IGY results.

The Sun sends out into space not only its light and heat but radiations of other wave lengths. Some are shorter waves than visible light, such as ultra-violet rays, X-rays, gamma-rays etc., while some are longer waves, infra-red, short radio and long radio waves, all travelling at the same speed as visible light, 186,000 miles per second. Occasionally flares occur on the surface of the Sun. These usually appear in the midst of active sunspot groups, and are isolated areas of sudden outbursts of intense ultra-violet radiations, X-rays and the mysterious cosmic ray particles with, in addition, the ejection of electrified particles.

The wave radiations all reach us in 8½ minutes from the time of the actual outburst, but the electrified particles travel slower, taking a day or two to cover the 93 million miles. Not only are our optical observatories, with their special solar telescopes, able to record the appearance of flares (which may last only a matter of minutes at their height) but the radio astronomers are able to pick up the emission on their particular wave lengths. Then when the electrified particles arrive we frequently experience a magnetic storm which displaces our magnetic needles (compasses) and, what is more important to us, upsets our radio telecommunication systems.

In our upper atmosphere there is a layer which reflects radio waves such as are used for long-distance communication. In fact it is this layer (in the ionosphere) which allows such communications between stations a long way apart – round the curvature of the Earth – as the waves are 'bounced off' this layer. If it were not

for this reflection the waves would travel out in a straight line into space and never reach their far destinations. When a solar storm occurs and the electrified particles from the Sun reach this upper layer of our atmosphere, they so transform it that it loses its reflective property and our radio waves go out into space for the period of the storm and thus our communications are disrupted. So, not only are our astronomers (optical and radio) interested in 'storms on the Sun' but our communications engineers seek ways of forecasting when flares are likely to occur, to be forewarned. This is not exactly possible at present, but research has provided some guides, and, in any case, it is natural that far more such storms can be expected during the sunspot maximum periods.

The last minimum occurred about 1964 September, so that the Sun's activity is increasing all the time as we approach the next maximum due about 1968–9. So the face of the Sun is very well worth watching at the present time.

The Sun ejects a constant stream of rays and sub-atomic particles (protons and electrons) and this radiation is recorded even from the 'quiet' Sun. One can say that there is a strong wind blowing continuously through the Solar System (known as the 'solar wind') speeding past the Earth at thousands of miles per hour. It will be appreciated that the effects are much stronger during solar storms, and the radio astronomers then record violent fluctuations in their instruments. The optical astronomers scan the Sun with their special solar instruments, some of which photograph in monochromatic light of particular wave lengths a picture of selected elements (gases) on the Sun, such as hydrogen or calcium, obtaining thereby pictures of the Sun and its surrounding 'atmosphere' containing those elements. X-rays do not penetrate our own atmosphere, but photographs of the Sun in those wave lengths, and in ultra-violet and infra-red, have been taken with cameras mounted in rockets sent to great heights where our air is very tenuous.

Hydrogen photographs taken in monochromatic light by our observatories show the flames or 'prominences' which rise from the Sun's surface but which are not visible by ordinary

light – see the cover picture in the 1966 *Yearbook of Astronomy*.

The electrified particles shot out from the Sun, which are mostly of hydrogen, are magnetically attracted to the magnetic poles of the Earth. It is there that the effects are intensified and, as stated earlier, this is why scientific bases in the Antarctic are so important. It is in the polar regions, too, that the particles illuminate the upper atmosphere with the glowing auroræ. Within the Arctic and Antarctic circles these displays of coloured lights in the form of rays and curtains are quite a magnificent spectacle, while during violent solar outbursts they have been seen in much lower latitudes. They are certainly seen sometimes in England and on the Continent, but they are much more common in Scotland.

The modern scientist has the advantage that he can now send his observing instruments by rocket or artificial satellite beyond the blanket of our atmosphere. In the higher regions of much rarer air, cameras attached to telescopes have taken first class photographs of the Sun's surface from unmanned balloons at a height of 80,000 feet. Free of the atmospheric turbulence, the photographs proved to have much better definition than any ever taken from the Earth, and the detail shown could hardly be bettered. With rockets, going higher still, plates have been recovered showing excellent pictures but in the case of satellites sent away beyond our atmosphere any photographs have to be transmitted back by radio techniques and some loss of detail is inevitable at present. However there is continual improvement as was evident from the close-up photographs taken by the space probes of the Moon and of Mars.

Orbiting solar observatories launched from the USA have made a special study of the Sun, particularly by taking photographs in ultra-violet and X-ray radiations. While so much has been learnt, the Sun still holds many secrets, but with modern instruments and techniques many will surely be revealed to us.

Space-travellers must have a glorious view of the heavens from their orbiting capsules, with the sky studded with brilliant stars. The outer layers of the Sun, with their prominences and the beautiful surrounding corona – seen by ordinary mortals only during the

brief moments of a total solar eclipse – would be a magnificent sight, the corona stretching much further out into space than has ever been seen from the Earth.

The launching of man into space is certainly spectacular, and captures the imagination of us all with the display of courage that it entails; but the scientist looks to satellites and probes, with all their sophisticated instrumentation, to provide more information about the Solar System, and the Sun especially.

Man in space has to face many hazards, not least of which are the dangers from the injurious rays and particles shot out from the Sun, and this is an aspect that will always have to receive the greatest consideration in the way of providing protection for the travellers, particularly during the periods of maximum solar activity. In fact it was reported that the Russians considered any attempt to reach the Moon would be dangerous after 1967 owing to the radiations from solar flares. Nevertheless, at the time of writing, the Americans seem bent on reaching the Moon in 1968 or soon after, so either their Gemini astronauts have found the hazards less than were anticipated or the 'race for the Moon' is looked upon as all-important! Perhaps by the time this appears in print the race will have been won.

A final word to any budding solar observer – never look direct at the Sun through a telescope, not even with a dark filter, as the concentrated heat at the eyepiece could instantly damage the sight. There are safe ways to observe the Sun telescopically, and anyone interested in taking up the study of this fascinating celestial object should familiarize himself with the correct techniques – for instance, by reading the article in the 1963 *Yearbook of Astronomy* previously mentioned.

Events on the Moon

B. M. MIDDLEHURST

Does anything happen on the Moon? For many years, it was widely held that the Moon was a cold, dead body, heated only from outside by the Sun, that it had no measurable atmosphere, and that all reports of changes were due to observational errors. Although the markings visible on its surface through a telescope include features called craters, and at least some of these have been believed by many to have been caused by internal activity, perhaps by volcanic eruptions, this was believed to have happened all in the past. Recently, however, new evidence has made it necessary for us to take another look at these ideas.

In 1963 at the Lowell Observatory in Flagstaff, Arizona, two observers, James Greenacre and Edward Barr, were engaged in lunar mapping and when checking details in the region of the lunar crater Aristarchus, they suddenly noticed unusual reddish glows in several places on the crater rim. The telescope was set up for visual observing and as it was not possible to change the eyepiece quickly for a camera, they watched and recorded the development of the changes until they faded about twenty-five minutes later. A month later, 1963 November 27, colours were seen again in the same general area by Greenacre and Barr, and this time they quickly summoned Dr John Hall, Director of the Observatory, who came within five minutes. Peter Boyce, observing at the Perkins Observatory 72-inch reflector, also saw the changes and gave independent confirmation of the details. This time, an attempt was made to record the phenomenon but, unfortunately, the intensity was not sufficiently high above the general bright background of the lunar surface and no trace of the unusual colour showed up on the film. However, the large number of observers made the reality of

the phenomenon certain. This time the colours lasted for about seventy-five minutes.

What had the Flagstaff observers seen? Many suggestions were made. Was it evidence of a lunar volcano, a sudden glint from a rock face, luminescence (e.g., by fluorescence), an escape of hot gas, thermoluminescence, or something else? The Russian astronomer, N. Kozyrev, had earlier, after several years' persistent watching, obtained spectral records from the Aristarchus region and others from the crater Alphonsus which showed unusual features; red glows had been reported at other times in Alphonsus also. Kozyrev's records were permanent, but for a long time, they, and Kozyrev himself, were much criticized. On the night of 1963 November 1–2, Z. Kopal and T. Rackham, observing at the Pic-du-Midi Observatory, also obtained a permanent record of an unusual red glow on the Moon. This time it extended over a large area around the ray crater Kepler. A strong enhancement of the brightness was shown in a photograph taken through a red filter, but in a photograph recording green light obtained immediately afterwards, nothing unusual was seen. The phenomenon appeared on two red photographs and apparently lasted a few minutes on each occasion. Nothing unusual could be detected on an intermediate one. No one else is known to have seen or recorded these events and Kopal and Rackham were also criticized adversely.

Most of the changes reported are transitory and involve small areas. In addition, the appearance of any lunar feature changes greatly with change in phase. It is thus easy for inexperienced amateur or professional lunar observers to delude themselves into believing that a feature has changed intrinsically, when in fact, merely the lighting conditions have changed. Many experienced lunar observers have never seen an event, even though they may observe often. Thus, although it was known that changes in many features had been reported in the nineteenth century, very strong doubts as to their reality had been repeatedly expressed.

However, the situation could be looked at rather differently. Let us see what happens if we admit for the moment that at least the Flagstaff observations (where, on the second occasion, five ex-

perienced and reliable observers had been involved) and the permanent records of Kozyrev, Kopal and Rackham, and others (about twelve in all) referred to real events. Once we admit this, we should again review the earlier records and here there is a surprise. During a literature search begun by the writer in 1964 and continued with the co-operation of Patrick Moore and many other astronomers, more than four hundred records with many common features were found. Moreover, they go back four centuries. The first listed recorded event occurred on 1540 November 26. This and another of 1587 were certainly spectacular; they were visible to the naked eye – the telescope was not yet invented and was not used for lunar observing until 1610. Both events occurred in the dark part of the Moon, and in each case there is no doubt that the observers thought they saw something on the face of the Moon. A contemporary engraving of the observer's impression in 1540 is reproduced in Plate 2a. The phenomenon lasted through two nights, and by the second, the 'star' had split into two comet-like 'flames'. Whether coincidence or not, there are now twin craters very close to the site of the 'star'. The observer of 1587, as recorded in Harrison's *Chronologie*, saw a bright spot on the dark side of the Moon. It is described as, 'a sterre is sene in the bodie of the mone vpon the [blank] of Marche, whereat many men merueiled, and not without cause, for it stode directly betwene the pointes of her hornes, the mone being chaunged, not passing 5 or 6 daies before'.

The observers of the events of 1540 and 1587 were anonymous, but the descriptions, if one makes allowance for the use of the word 'star', are concise and clear. There is no reason to suppose that they have distorted the details.

In the next century, six reports are known, of which three are by J. D. Cassini, Director of the Paris Observatory. In the eighteenth century, we have reports by Halley, de Louville, de Ulloa, Herschel, Schröter, and Bode, among others, and there are forty-eight reports in all. Halley and de Louville saw 'lightning' on the face of the moon during an eclipse; de Louville's report from Paris, France, was for 1715 May 3, and Halley's, in England, was for

1715 April 25. It was the same eclipse, but England was still using the old calendar which at that time differed by eight days from the Gregorian, already adopted in France. During another eclipse, in 1778, the Spanish admiral, de Ulloa, reported a hole in the Moon through which he said he could see the Sun. The observation was ridiculed on the grounds that the hole would have to be hundreds of kilometers long, but if de Ulloa described what he saw correctly, it could have been an extremely bright spot on the dark surface of the Moon. In eclipse observations, attention is usually paid to the solar corona, but the eclipse also brings the Moon into view. It should, of course, be remembered that at this phase (New Moon) earthshine is greatest and bright areas would show up. Nevertheless, this explanation does not fully account for the variations in brightness of the different areas.

In 1783, and again in 1787, Herschel reported 'volcanoes' on the Moon. At least one of these was located in the crater Aristarchus, and in reading the description of his observations, one may be struck by other similarities with the Flagstaff reports nearly two hundred years later. There is one important difference; Herschel's observations were on the dark side. The report of the 1787 'volcanoes' was published in the *Philosophical Transactions of the Royal Society of London*, but that of 1783 was described only in a letter to Herschel's acquaintance, Magellan, a Portuguese astronomer then living in London.

J. H. Schröter, who was Chief Magistrate at Lilienthal in Germany at the end of the eighteenth century, was a friend of Herschel and a keen lunar observer. He had at least one excellent telescope and, though an indifferent draftsman, was a good observer and reported many bright spots on the dark side, though he was puzzled by the many changes in relative brightness which he saw and recorded, particularly for areas in the Aristarchus region and for the craters Menelaus and Manilius. In 1788, Bode published a paper on the subject of lunar 'volcanoes' that was written with eloquence and scorn, dismissing all the anomalous appearances as due to earthshine. Curiously, however, though he must have known of other reports, he bases his argument on about

half a dozen cases. Earthshine is strongest at New Moon, when eclipses of the Sun occur, and is significant for two to three days before and after. The dated records among our list of four hundred occur fairly uniformly throughout the whole lunation, apart from two days before and after New Moon. Bode's eloquent argument thus fails for about eighty per cent of our records, even if we concede the point for the rest; however, there are statistical arguments described below that suggest that we should not even do that.

Schröter kept and published a complete record of his lunar observations up to 1790 (in *Selenotopographische Fragmente*, published in 1791), and in it can be traced his reaction to Bode's dismissal of the bright spots. At first, he accepts the argument of Bode, when he considered to be a more distinguished colleague; then, gradually, doubts creep in. At the end, he devotes a whole section to the phenomena – bright spots on the dark side, colour changes, changes in relative brightness and the eclipse observations – and it is clear that he is no longer convinced by Bode's explanation. All through the book, in meticulous and tedious detail, down go the observing data – date, time of day, weather, altitude of the Moon, and phase – and it is a marvellous record.

Many of Schröter's later observations are lost. The early part of the nineteenth century was a turbulent time with armies ranging over Europe. In 1813, the rabble of Napoleon's army retreating from Moscow overran Schröter's property in Lilienthal, and his house, observatory, telescopes, and many of his manuscripts were all destroyed. If they had been preserved, no doubt we should have had more records of lunar bright spots on the dark side. The catastrophe broke Schröter's spirit and ruined him. He was already an old man, and though he lived on a few more years, he did little or no more observing.

A gap in the records from 1800 to 1820 may also be due to the unsettled state of Europe. No lunar events are known to have been recorded for this period and it was indeed a difficult one in which to practise astronomy in Europe.

In the nineteenth century, nearly every observer of note is on record as having observed transient changes of some kind. Bright

spots on the dark side are now less frequent, but as larger and better telescopes were coming into use, this is not surprising. The higher powers needed resulted in smaller fields of view, and the dark side was therefore not so often watched. At the same time, observation of more detail was possible and reports of obscurations began. We have three such reports from E. E. Barnard, and many others from W. H. Pickering. Piazzi, Olbers, Argelander, Tempel, Elger, and many others are on record as having seen earlier changes.

Obviously, it would be a serious matter to disregard such a large number of reports by so many eminent astronomers, so we may presume that at least some of them describe real events. If some are due to errors of observation, statistically this will not matter much unless the errors are in the majority, because, except in regard to lighting conditions, i.e., phase, these would be randomly placed with respect to almost anything. If we analyse the reports, any significant features should still show up in the distribution, but there will be a larger amount of background.

Most interested people are now agreed that at least some of the reports represent actual happenings on the Moon. The differences are in the interpretations, and we shall consider the most important suggestions here: (1) luminescence, an afterglow caused by bombardment by UV light or protons from the Sun or other outside sources of energy; (2) thermo-luminescence, a glow caused by the heating up of certain kinds of rock – this must occur always at the same time after lunar sunrise; (3) explosions due to meteor impact; (4) internal causes, such as vulcanism or, more probably, outgassing. Also, the possible effect of the Earth's magnetosphere will have to be taken into account, and Dr Jack Green has suggested that heating due to tidal friction should also be considered.

Luminescence would be a very satisfactory explanation for the bright spots and colour changes if it could account quantitatively for the amounts of extra energy released, but unfortunately, laboratory experiments on efficiency rates for fluorescence of rocks and meteorite material likely to be similar to the Moon's surface are not very encouraging. In addition, there would have to be a periodicity

related to the synodic month (from New Moon to New Moon) which does not exist. This would be true also for thermoluminescence (2), i.e., enhanced radiation from certain kinds of rocks due to heating. There is also no connexion to be found with the solar cycle as measured by relative sunspot numbers, though it was at first thought that there was. Flares certainly release large numbers of very energetic protons (though unfortunately, not enough), but there is not much data on flares, and the earliest records cannot be tested against them. Montly sunspot records go back consistently to 1749 and there are some yearly records back to 1610. The luminescence theory is improved a little if the effect of the magnetosphere of the Earth is taken into account. Charged particles trapped in the magnetosphere tail can be accelerated to much higher energies and, at or near perigee, the Full Moon can be located inside the comet-like tail of the magnetosphere as it streams away from the Sun. However, only a small number of events happen near Full Moon, and even if these could be accounted for in this way, we should still need an explanation for the others.

Meteor impact could be expected to cause explosions visible from the Earth once in a while. The lack of lunar atmosphere would allow meteors to reach the surface without the tremendous reduction in size and speed that occurs for them as they rush through our own, so that the amount of energy produced in the explosion would be much larger for a meteor striking the Moon than for a similar one hitting the Earth after losing much of its mass in our atmosphere. Nevertheless, there are some objections to using the meteor impact theory to explain all our four hundred events. For one thing, it is not likely that the after-effects would last for more than a few seconds, but a typical duration for a transient event is from fifteen minutes to an hour. Then there is the strange case of the 'flashing lunar mountain' for which Brian Warner reported short flashes repeated in the same location on the dark side – hardly due to meteors all falling in the same place.

Finally, if one plots the sites of the events on the lunar surface, a very significant pattern emerges (Plate 2b). All the sites that we have so far listed are (1) ray craters, such as Copernicus, Kepler,

Thales, and Proclus, (2) ring plains with dark floors or with dark patches on their floors, such as Plato, Schickard, W. Humboldt, and Alphonsus, or (3) sites (peaks or craters) near the edges of maria (around Mare Imbrium – the largest mare – there are two rings, one inside the other). Apart from the ring pattern, which is just what could be expected around dying volcanic fields, some interesting chains of crater sites can be found. One has to be fairly careful in tracing patterns among so many points, as patterns may arise by chance and unless they can be physically justified in some way, they should be disregarded. But much other evidence suggesting volcanic activity, at least in the past, has been found on the Moon, and the close-up photographs from the Rangers, Surveyor, Luna 9 and the Orbiters confirm this, so it is not unreasonable to regard the ring patterns at least as consistent with previous activity. The consistency of the patterns makes it almost certain that the majority of the reports are, after all, reliable, and also that some internal activity continues up to the present time. The distribution also provided a link between ray craters and internal activity, and between dark deposits on ring-plain floors and internal activity. A point in Alphonsus was chosen as the target for Ranger 9 because of the dark deposits, the reports of glows, and of Kozyrev's spectra; it is not widely realized that the reports of activity in Alphonsus go back to 1937. Plato, with one of the darkest floors, is one of the most active sites on the Moon if we are to believe the reports – there are 29 – and only the Aristarchus region, with 112, has more.

A few words should be said next about lunar tides, that is, tides on the Moon caused by the gravitational pulls of the Earth and the Sun. Tidal forces on the Moon are proportional to GMr/R^3, where r is the radius of the Moon, R the distance of the attracting body, M its mass, and G a constant (the constant of gravitation) which we need not consider further here. The forces pull the surface of the Moon away from the centre and on the Moon, very roughly, since much the same face is always towards us, they always act in much the same direction. The only thing that changes is the amount, and this depends on R. At perigee when R is least, the

tidal force is greatest, and at apogee when the Moon is most relaxed, it is least. Between any two points on the Moon, there will be a stress caused in a similar way. In a liquid (e.g., the sea), the particles slide over one another under tidal forces; in solid material, if the stress is great enough, cracks may form where the material is weakest. A moment's reflection will show that the attraction of the Earth, 81 times heavier than the Moon, will produce much larger stresses on the Moon than vice versa. Also, because the Sun's pull is the same for both, it will be much less important for the Moon relative to this larger force, and thus can be neglected unless we are to do very exact calculations.

The tidal situation on the Moon is thus relatively simple and the distribution of the events around the orbit (the anomalistic month, ~27·6 days) is certainly worth investigating. What we find is that the events occur much more frequently near perigee where the gravitational stresses are greatest, and that there is a smaller concentration at apogee. The apogee peak was rather disturbing at first, as it did not seem to fit in very well with the tidal theory. However, as the number of reports has grown from 100 to 400, the peaks have continued to persist. An analogy was finally found for the periods of low tide on the Earth, so that an explanation is available. C. L. Pekeris and others have pointed out that a rise of a few inches in the level of certain oil and water wells far from the sea (and otherwise unaffected by drainage) can be explained as a squeeze due to the settling of the layers on to the reservoir of oil or water as the Earth's crust relaxes. So if there were pockets of gas or other material capable of being squeezed out from beneath the lunar surface, at apogee some such effect could act in a similar way.

So, on the whole, it looks as if at least some of the events, and probably a majority of them, are due to release of fluids and dust from beneath the lunar surface. The short duration of most of them is not very surprising since the material would be released into a vacuum much more absolute than any that can be achieved in a laboratory on the Earth and would dissipate immediately.

Even so, the cause of the glows is not yet at all clear. Some of

the underground pockets could be very hot. Many 'hot spots' have been charted by Shorthill and Saari, and by Low, and some of these do coincide with the sites of events. It is not likely that there would be a complete correspondence, as for some sites no activity has been reported for many years and all are not equally active. In fact, there are 'hot spots' that have not been reported as sites of events, and sites of events, such as Eratosthenes, that show no thermal anomaly. The cause could also lie in some kind of electrical glow discharge. This is not unknown in volcanic areas on Earth, e.g., Surtsey in Iceland, which has almost constant thunderstorms over it, but the analogy is not really good, as the meteorological conditions on Earth are without parallel on the Moon. Fluorescence may play a part, though probably not on the dark side, and thermoluminescence has been suggested.

Thus this article can only be regarded as interim and much more work is needed. The statistics suggest fairly conclusively that the Moon is not, after all, entirely inert, and although several different types of phenomena may be involved, it is likely that outgassing plays an important rôle.

Since 1963, the increase in interest in lunar events has brought in many more reports, but it also means that many relatively inexperienced observers are involved. Also, there are now more than a dozen permanent records of anomalies. These confirm the pattern of the sites shown by the historical records and there is a marked concentration around perigee.

The Moon Blink programme began in 1964, and a somewhat similar one is operated in Britain by members of the Lunar Section of the British Astronomical Association. Observers in Japan, Russia, and Australia are also interested and in time we should be able to achieve an almost round-the-clock watch of the Moon. About half a dozen events have been reported by the B.A.A. Lunar Section during 1966, and a similar number by the American Astronet group. As the number of lunar observers grows, we should be able to get a better idea of the true frequency and perhaps even obtain a few more permanent records.

Mantle Convection in the Moon

S. MIYAMOTO

Introduction

For a long time the Moon was thought to be completely dead, with changeless surface features. This is true in a sense, since there can be no erosion without atmosphere and water. However, recent observations suggest that some activity persists; for instance a gaseous ejection in the crater Alphonsus was observed by N. A. Kozyrev in 1958, and subsequently red colour phenomena have been seen on several occasions, notably in the Aristarchus region by J. Greenacre and E. Barr (1963) and near Gassendi by P. K. Sartory, Patrick Moore and others (1966). Researches by B. M. Middlehurst, J. M. Burley and Moore have listed several hundreds of 'lunar events' since 1540, though of course not all the reports are reliable. Yet lunar activity of a mild type does seem to occur.

Estimates of the Moon's internal temperature are relevant in this connexion. If the Moon were formed by accretion, and assuming the normal percentage of radioactive substances (about $1:10^8$ in weight; the half-life is 13·9 thousand million years for thorium-232, 4·5 thousand million years for uranium-238), a simple calculation shows that the temperature inside the Moon must now be higher than the melting points of rocks.

The possibility of mantle convection in the Moon, as in the Earth, was first proposed by Runcorn to account for the pronounced earthward bulge of the Moon. Such a bulge cannot be explained by the tidal pull of the Earth, even if we assume that the Moon's distance from the Earth used to be less than is the case now. Therefore, Runcorn put forward the idea of mantle convection directed toward the Earth.

Mantle convection would have a strong influence on the moulding of the crust. It seems that studies of the present-day surface features of the Moon, on geological principles, will therefore be highly informative.

Spurr's 'Selenological History'

The late J. E. Spurr, the American geologist, worked out the Moon's probable geological history by means of a thorough analysis of the crustal features. His conclusions may be briefly summarized here. According to Spurr:

(1) The Moon's surface was originally fluid. By cooling, together with gaseous ejection, the first plastic crust was formed; this was covered with large and small craterlike depressions, due to the escape of gases, and there were also faults and fissures produced by the lateral pressure of the shrinking Moon. This *primitive complex* must at one stage have covered much of the surface of the entire Moon. A remnant example is seen in the Faye-Parrot region. Crater walls and ridges tend to be 'wavy', as though crumpled and contracted, and are traversed by fissures and faults. A similar maze of ridges is seen in the Taurus area; also south of Schickard, and east and south-east of the Mare Nectaris.*

With increasing thickness of the siliceous crust, and the shrinking due to gas ebullition, the polar grid fissure-fracture system developed. Networks of tectonic lines may be clearly seen in the south polar region and in the south-east. Many of the fissures are indurated by gas ebullition and accompanying silicification. In the north polar region, 'cemented' fissures remained as ridges, where portions of the crust sank in blocks due to gas ejection or appression forces.

When the gas pressure increased under the crust already showing the grid system, parts of the crust were lifted up in blocks, using the fissures as sliding planes, instead of in the usual circular structures. Following the escape of gases, the uplifted blocks

* *East* and *west* are here used in the classical astronomical sense; west is on the Crisium side, and east on the Oceanus Procellarum side of the Moon.

dropped down once more, producing the so-called *grabencraters*. Here, the original grid system was adopted as parts of the crater walls, leading to craters which are often polygonal in outline. Examples of very old grabencraters are Parrot, Faye, Sacrobosco and Maupertuis.

At the end of this era, the uplift of the gigantic Imbrian dome was commenced by the formation of a gas reservoir under the thickening crust. The Crisium, Humorum and Serenitatis domes were also giant uplifts produced at the close of this *Proteroselene* era.

The first differential slippings of the plastic crust were also seen, such as with the well-known east-west Cichus fault, together with faults to the east and southern sections of the central meridianal horst.

(2) The second revolutionary era, characterized by the collapse of the Imbrian and other domes with the consequent formation of maria, is known as the *Mesoselene* in Spurr's terminology. Radial and concentric fault systems developed surrounding Mare Imbrium, while Mare Frigoris, Mare Vaporum, Sinus Æstuum and other features were produced as circumimbrian troughs. The Apennine and Carpathian 'coastal' mountains were cut by radial fault systems.

Many other far-reaching events were due to the Imbrian dome collapse. For instance, the breccia fields in Palus Nebularum and west of Alexander were produced by the shattering of the outer surround of the Imbrian dome. The intense remelting of the crust was also due to the magmatic activity stimulated by the Imbrian event. In the south-eastern continent, the thickness of the siliceous crust was greatly reduced, and dark basic magma outcropped in places – as in the interior of Schickard and the dark areas near Clausius. Where the crust was thicker, however, the remelting was not so marked, and crater floors were merely flattened by partial melting; examples are numerous in the southern continent (Stöfler, Clavius, etc.). Crustal slipping has offset the coastal Imbrian heights by about 190 kilometres into the present Caucasus and Alps in the region of the crater Cassini.

This was also the main period of crater formation. The north polar region, for example, is a field of grabencraters. Domal uplifts and collapses of the Ptolemæus and Clavius type, the subsequent formation of most of the caldera-craters such as Copernicus, Theophilus and Tycho were also produced at much the same time. Caldera-craters have terrestrial analogies; they are due to gas and magmatic activity, with uplift and subsequent collapsing of the crust, while in some cases material is spread beyond the walls. These caldera-craters are more circular than the grabencraters, and inflation and subsidence affects the surrounding areas as well as the interiors. Examples of this are seen in the circular depressed zone around Tycho, and the extensive outer slope of Caroline Herschel.

The outer walls of some craters, notably Copernicus and Aristillus, are cut by systems of gullies. It has been suggested that these patterns were caused by running water or by *nuées ardentes* along the slopes, but the present outer slopes are very gentle, which suggests later depressions.

Craters are often deformed by remelting and by appression. This east-west appression is global. For instance, the northern and southern parts of the crater walls of Eratosthenes and Piccolomini are affected and partly broken; Copernicus and Arzachel show elongated forms along the meridian, due to appression, and the northern and southern parts of the crater walls are embellished with the so-called 'beak' patterns, which are made up of networks of faults and ridges running from SW to NE and from SE to NW, produced by the east-west appression and subsidence of the surrounding area which left a beak-shaped highland.

During this era, older craters showed renewed activity, as is shown by evidence of crater growth, broad upswellings and subsidences. These repeated disturbances complicated the crater structure. Partly destroyed older formations may be found disturbed by younger features; thus Agrippa was produced in the Mesoselene, and lies in the southern part of an older, largely ruined Proteroselene crater. Hainzel, also Mesoselene in date, is

parasitic to an older and larger Proteroselene crater extending to the south.

Toward the end of the era, the subsidence of the eastern area of the central meridianal horst caused lava flooding, creating the Mare Nubium with its many ruined craters. The Oceanus Procellarum, an extensive depression zone in the eastern half of the Moon, is also Mesoselene in age.

(3) The last active area, the *Teleoselene*, began with the solidification of the mare surfaces. Later, there occurred renewed deepening of the marial basins, with lava flooding over the surface. This new, darker lava may be seen in places, as along the south, west and north-west borders of the Mare Serenitatis. Also, the darker lava produced an irregular pattern on the surface of the Mare Tranquillitatis.

Wrinkle-ridges on the mare surfaces were formed at this time, some of them extending into the continents and becoming fissure-faults or craterlet-chains. The best examples of this are the wrinkle-ridge in the southern part of the Mare Imbrium, connected with the fault-fissure and crater-chain system between Copernicus and Eratosthenes to the south; and the wrinkle-ridge to the east of Plato, which enters the continent to the north and becomes a fault ridge, subsequently becoming a wrinkle-ridge again in its extension into the Mare Frigoris. These examples suggest that the features were controlled by the fissure system in the solid layer deep below the fluidal layer.

Young craters of the Teleoselene era are circular in form, with rather simple structure (Abulfeda, Arago, Sabine, Mösting). However, the most spectacular events of the period were the ash explosions, through fissures or small orifices from older craters such as Tycho, Copernicus, Kepler, Proclus and Byrgius.

The final manifestations of activity were the small *blowhole craters* in the maria, together with the opening of fissures in both maria and continents. The Hesiodus fissure, running east-west along the shore line of the southern Mare Nubium, and the Hyginus and Ariadæus fissures are Teleoselene and Late Mesoselene respectively.

The Imbrian Dome and Mantle Convection

As with the Earth, the siliceous crust on the surface of the Moon may be the produce squeezed out by the differentiation of ultra-basic substances of the mantle. The reaction principle in petrology states that under the influence of gravitation, a cooling magma will show separation of the heavy metallic crystals, which will sink downwards, leaving the more siliceous remaining liquid to form the upper layer. Radioactive atoms are too large to enter into the lattice of mineral crystals, so that they too are squeezed upward with the gases and lighter silicates.

In view of this, there seems to be an inherent difficulty to the inflation dome model. Spurr himself noted that 'provided the dome is broken and collapsed, why did the hardened lighter crust sink into the darker fluidal magma? – although morphological features suggest that it did'. In fact, this is the reverse process of the reaction principle; the fluidal magma of the mare, absorbing the siliceous crust, must presumably be removed before cooling. This difficulty may be removed by introducing the idea of mantle convection.

As is well known, the distribution of maria and continents may be controlled by the mantle convection pattern. In brief, continental blocks are drifted together over the inlet of convection, with maria being formed over the outlet. The fact that the Moon's averted hemisphere is mainly continental, and that the maria are concentrated on the Earth-turned portion, seems to indicate the simplest type of mantle convection – that is to say, the convection current was directed from the centre toward the Earth, and reached the surface on the Earth-facing hemisphere. This agrees well with the evidence that the Moon lacks a heavy core, since the convection pattern suggested here would be the most probable type for a 'coreless' globe.

Another property of mantle convection is the periodical nature of its activity. After every half-turn of the convection cell, the current stops for a while before starting another half-turn. The main cause of this behaviour must be the accumulation of radioactive heat within the Moon. The mantle is heated up from below,

and convection starts; after the half-turn, the cooler surface rocks sink down, while the hotter interior rocks are uplifted. This results in a thermally stable condition, until, after a long time, the surface rocks are cooled and the interior rocks heated up again. The mantle then becomes thermally unstable, and the convection process begins anew. The periodical nature of lunar activity may, then, not be in disagreement with Spurr's analysis: the era of original crustal formation, the second era with the Imbrian and other giant domes inflating and collapsing, and the third era of the revival of crater activity, together with ash explosions.

There seem to be two possible explanations of the primitive complex. According to Spurr, a siliceous primitive complex once covered the whole of the Moon's surface. Another possibility is that the siliceous matter 'floated' in blocks over the basic liquid of the maria. In this second model, the maria may be supposed to be as old as the primitive continental blocks; it is necessary to suppose that the maria surfaces became solid at the end of each active era, only to be remelted at the beginning of the next period of activity. This would mean that the Imbrian event would be succeeded by numerous smaller gas reservoirs under the hardening crust. Yet this does not affect the essential part of Spurr's theory.

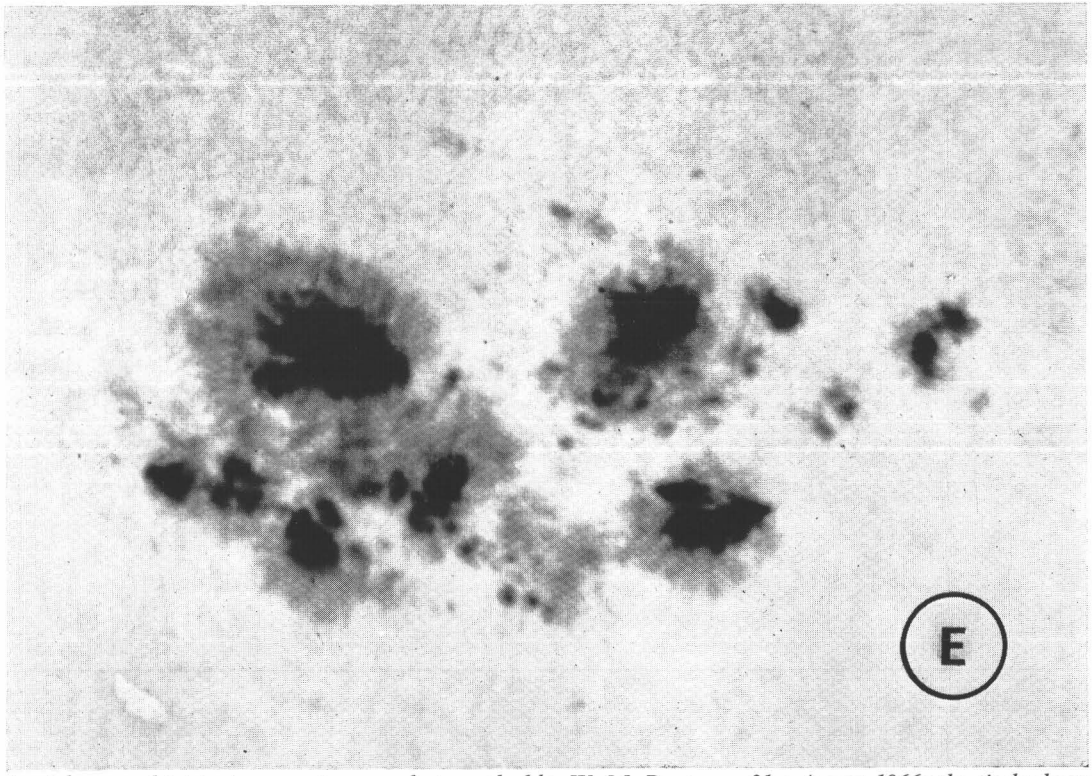
With this alternative block-model, it is not necessary to assume uniformity of the siliceous continents, so that there is no need to maintain that the dark patches in the south-east continent were produced by strong remelting. Even in the maria, there are ample reasons for supposing that a thin floating siliceous 'film', with minor convection turbulences in the fluidal mare surfaces, would produce the so-called ghost craters and isolated siliceous islands. Is Flamsteed a lava-flooded crater, or is it made up of 'unfinished' siliceous fragments arranged in a circular form by mare turbulence? (Here, the reference is to the large, rather low-walled formation, and not to the small, clearly younger crater.) All around may be seen an impressive correlation of fragmental walls and wrinkle-ridges. With the maria themselves, repeated melting of the basins will account for the irregular patterns such as those seen in the Mare Serenitatis and the Mare Tranquillitatis.

Half-Turn Period of Mantle Convection

On average, the velocity of the mantle convection current in the Earth is thought to be about 10 centimetres a year. A rough estimate of thermal transportation suggests that the velocity of mantle convection inside the Moon is about 2 per cent of that of the Earth; therefore, a half-turn in lunar convection must take about 2,000,000,000 years.

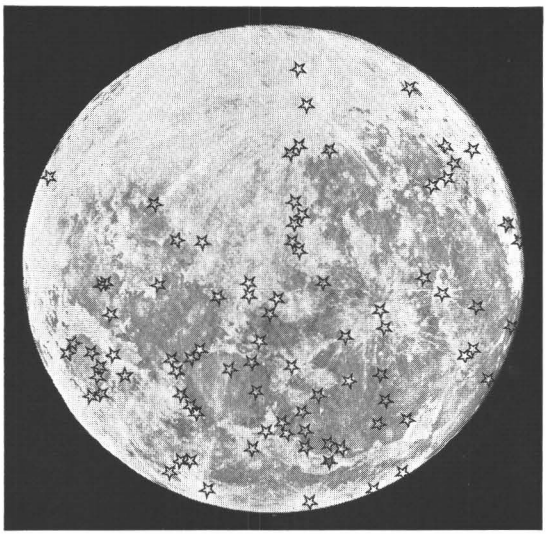
Therefore, we may expect that there have been two or three active phases in the Moon's history, which agrees well with Spurr's geological analysis. For the Earth, it has been claimed that the Pre-Cambrian active eras corresponded to changes of the convective pattern with the growth of the Earth's liquid core, and three orogenic eras have been worked out, the last of which was the Alpine. The mean period of half-turn activity is 200,000,000 years, which is in good agreement with the theoretical estimate.

The Moon may have been 'born cold' by the accretion process, but it later produced enough energy to make the surface features we see today. Do recent 'events' suggest that we are at the dawn of a new active era? The present-day Moon may be inert or active, but in any case there are strong reasons to suppose that its activity is periodical and its present state transitory.



1 A large and intricate sunspot group photographed by W. M. Baxter on 31st August 1966; the circle shows the earth to the same scale.

2a A contemporary record of an event on the Moon in 1540. The phenomenon lasted through two nights, by the second, the 'star' had split into two comet-like 'flames'.



2b A plot of the sites of events on the lunar surface over the last four hundred years.

The Barwell Meteorite

H. G. MILES

On Christmas Eve 1965, just as it was getting dark and when most people were making their final preparations for the following day, there suddenly appeared in the sky above the City of Coventry an orange-red ball of light with a long yellow tail moving rapidly in a northerly direction. This was followed a short time later by a very loud bang, just like that made by an aircraft travelling faster than sound. Some people phoned the police, some the local airport, but no-one could give a satisfactory explanation. The general feeling was that it would all be explained in the local press after the holidays.

Meanwhile, in the village of Barwell, just north of the hosiery town of Hinckley, strange things were happening. One of its residents, Mr Crow, was walking home from work along a road called 'The Common' when he saw a flash in the sky and then heard a bang. A few moments later he heard something swish down out of the sky and land quite near with a thud. He then heard four or five more objects come down in quick succession, the last one landing in the road near by, a piece of it breaking a window in the house of his neighbour, Mr Grewcock. Mrs Grewcock, who happened to be in the house at the time, heard the glass breaking and called to her husband. He went to the front of his house and found pieces of rock and white powder covering the pavement. He went to pick up a piece of the rock but it was too hot to handle. Apart from clearing up the mess, neither he nor Mr Crow did anything about it until after Christmas. Further down the road, another resident, Mr England, noticed on Christmas morning a dent in the bonnet of his car which he had left in the drive the previous afternoon. He suspected that children were responsible

and threw the lump of rock which he assumed was responsible for the damage on to the waste ground on the opposite side of the road.

With the festivities over and the return to normal life, Mr Grewcock reported the incident to the police. On the morning of December 27 he explained to Police Constable Scott what he and Mr Crow had seen and gave him the lump of rock which he thought had broken the window. Later on Constable Scott took a statement from Mr Crow and collected more 'samples'. He submitted his report and the samples to his seniors and the samples were forwarded to the Museum at Leicester and then on to the British Museum in London.

Stories of the strange object in the sky over Coventry and the surrounding areas appeared in the local press and on December 28, a spokesman at Elmdon Airport, Birmingham suggested that the 'fiery object' may have been a meteor. The author, who lives in Coventry, had seen the flash of the fireball as it swept across the sky and heard the sonic boom. In fact, it shattered an electric light bulb in his house. The idea that it might have been a meteor suggested the possibility of the re-entry of an artificial satellite which would produce identical phenomena. Consequently he immediately started to collect details of the event. Gradually the news from Barwell leaked out and it was soon realized that the events at Barwell and the objects seen in the sky over Warwickshire were very closely connected. On January 6, twenty of the country's leading geologists descended on the village in search of further fragments of the stones, which had now been identified as meteorites. Appeals were made to the local residents to hand in any specimens they had collected. Very soon just over 50 lb had been recovered, but later, when very favourable rewards were offered, the total weight went up to just over 98 lb.

This makes the Barwell fall the heaviest recorded meteoritic fall in England and the second heaviest in the British Isles. The table gives a list of the falls since the turn of the century.

1902 Crumlin, Northern Ireland	9 lb 5½ oz
1914 Appley Bridge, Lancashire	33 lb

1917	Strathmore, Perthshire	29 lb 8 oz
1923	Ashdon, Essex	3 lb
1931	Pontlyfni, Caernarvonshire	?
1949	Beddgelert, Caernarvonshire	1 lb 12 oz
1965	Barwell, Leicestershire	98 lb approx

The heaviest occurred at Limerick, Ireland, in 1813, where the meteorite had a total weight of 106 lb.

On January 8, I visited Barwell and was shown by Constable Scott the various places where the fragments had been found, and in the afternoon searched the fields to the west of the Common and found eight small fragments. By this time I had collected sufficient information to give a reasonable value for the track of the fireball, but even at this early stage there was contradictory evidence which at that time could not be explained. It was obvious that many more reports were needed and an intensive campaign was started using the Press, radio and TV. Dr Meadows of Leicester University collected further reports. I interviewed most of the people who lived in the Coventry area who submitted reports, because it was considered that this was the only way in which the maximum information could be obtained. Much of South Warwickshire was combed for further observations, and many useful reports were collected. In addition, reports were received from a wide area stretching from Wiltshire in the south to Shropshire in the north, from Port Talbot in the west to Colchester and Grantham in the east. Within this area, there were well defined regions where no or very few reports were received. This was due mainly to the large amount of cloud that existed. This cloud cover was very patchy, resulting in one observer reporting only very small breaks in the cloud layer and yet another only a short distance away reporting a relatively clear sky.

Most of the observations made from Coventry described an object through breaks in the cloud, and it soon became obvious that these people had not all seen the same object. Some reported virtually an overhead passage, whilst others described an object passing low to the east. A second fireball was suspected, and later this was confirmed when an observer from Rugby saw an object

more or less overhead and a few moments later saw a second object passing over Coventry. Up till this time it had been assumed that the 'Coventry' fireball had been responsible for the fall at Barwell. It was therefore necessary to check this, because from the information available at that time it could feasibly have been this second object. The correctness of the original theory was confirmed by two methods.

An examination of the positions from which meteoritic material had been recovered showed that if they conformed to the usual pattern, in which the positions were restricted to an ellipse in which the direction of the major axis coincided with the direction of flight of the fireball and that the smaller fragments were to be found towards the end nearest to the direction in which the fireball approached, then there was a well defined part of this ellipse in which no meteorites had been found. A thorough search of this part was made by the author and others, including the Editor of this book, Patrick Moore, and three large fragments were found. This restored the balance, and showed that the major axis pointed in the direction of Coventry and not Rugby. Secondly, the reduction of the many observations from the areas of Coventry and Rugby received later showed that without doubt that the fireball that passed over Coventry was responsible for the fall.

Even with the identification of the second object, there were many other observations, some from Coventry, some from Loughborough and other regions of Leicestershire and other from Staffordshire, which could not be fitted into this picture. The matter came to a head when observers from Coventry reported seeing a fireball from their west-facing windows. The identification of this third fireball cleared all the principal difficulties raised from reports from Warwickshire and Leicestershire. There were, however, still three well defined groups of observations which could not be fitted into the above picture.

Although some of the Staffordshire reports could be linked with the third fireball, others from this area and from Cheshire and Shropshire could not be so associated with any confidence. These reports together with observations from Port Talbot, Nottingham

and Bristol indicated that a fourth object had crossed the sky on a track roughly parallel to the others but passing well to the west of Coventry.

The second group of observations came from an area which included the counties of Buckinghamshire and Berkshire. These reported a single object falling directly downwards in the north, some saying that it was to the east of the north line. These together with some reports from Northamptonshire and Leicester suggest the possibility of the existence of a fifth object, although it is by no means conclusive. It is strange, however, that none of these southern reports mentioned more than one object, although this could be explained by the presence of extensive cloud.

The last group all reported an object travelling in a south-westerly direction in a line extending from Grantham in Lincolnshire to Stroud in Gloucestershire. Unfortunately, these reports have not yet been explained, although it is fairly certain that they had no connexion with the Barwell incident.

To help in the identification of the various fireballs, a code letter has been assigned to the individual members, the actual code being similar to that used in the official reports.

Fireball 1

This travelled in a NNE direction passing over the eastern boundary of Coventry, and resulted in the fall at Barwell. The track of this object has been determined to quite a high degree of accuracy. Several observers reported a virtually overhead passage, and on interview were able to indicate whether the track was slightly to the west or to the east. An observer from Barwell saw the fireball descending directly downwards in the south-west, although she did not see the extinction point. Reports from the Coventry area indicated that the fireball went extinct at a point just beyond the north-east boundary of Coventry. The area between the city and Barwell was searched very carefully for observers. Although over a hundred people were interviewed, not one was found who had seen anything, although some had heard thunder. This is in accordance with the usual behaviour of a medium sized object. As

the meteor enters the atmosphere it is slowed down by air resistance. This resistance increases considerably when it penetrates the lower and denser regions. A certain point is reached, usually near the tropopause, i.e. the lower boundary of the stratosphere, when the speed of the object is no longer sufficient to generate enough frictional heat to keep the meteor glowing. At this point, most of the cosmic speed has been lost and the meteor moves solely under the influence of the Earth's gravitational force. In this case, the extinction occurred at a height of about 10 kilometres.

As with all the other objects, the description of the fireball varied considerably, due no doubt to some observers seeing the object through breaks in the cloud and others seeing it through thin cloud. It is fairly certain that just before extinction was reached, it developed a long yellow tail. Observers from Warwick and Kenilworth reported generally only a short one. The colour of the fireball depended on the direction in which it was seen. Those who saw it after it had passed over likened it to the after-burn on a jet engine. Most agreed that it was about half the size of the Sun and about as bright as the setting Sun. As it passed over Kenilworth, one observer described how the flood waters appeared red in colour.

Fireball 2

This travelled on approximately a parallel track to the previous fireball, but to the east, passing nearly over Rugby and becoming extinct just south of Leicester. This object was seen over a much wider area, although there were some regions where very few observations were received. It descended at roughly the same angle (20° to the horizontal) and had a similar extinction height, although its behaviour at this point was entirely different. Two observers reported the object blowing up, forming four major fragments, one piece shooting upwards and the other three downwards.

The appearance of this fireball was similar to that of fireball 1, although there were some important differences. It was reported

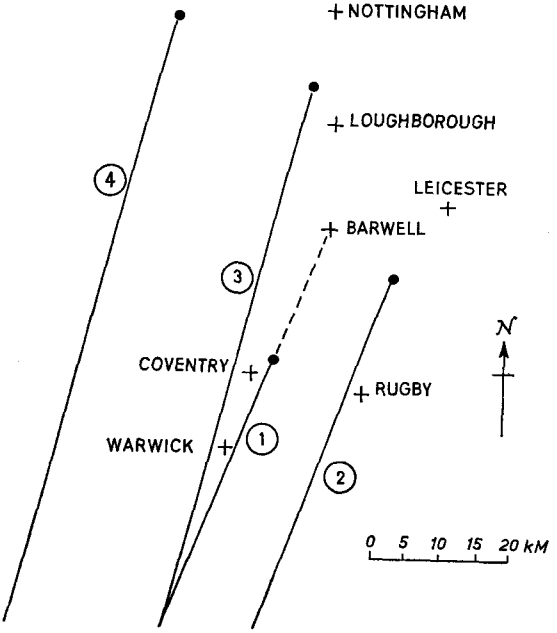


Fig. 1. Tracks of fireballs

generally as orange red in colour, but earlier along the track it was reported as much whiter. The dust trail left behind was definitely corkscrew in shape, and persisted for several minutes. The dust trail for No. 1 was described as straight, and it did not persist for very long. Just north-west of Rugby the characteristics of the bolide changed when it appeared to explode. The descriptions after this do not agree very well, but this may have been due to interference by cloud.

The sonic effects from this fireball were particularly severe, and were recorded over a wide area. It was the sonic boom from this object that caused the difficulties in the early analysis of the Coventry reports. A large percentage of the reports from Coventry mentioned either a delay of about thirty seconds between the sighting and the boom or a delay of one and a half minutes. It

is now believed that the thirty-second delay reports are linked with fireball 1 and the one-and-a-half-minute delay reports are associated with No. 2, the extra time being required for the sound to travel the distance from track 2 to Coventry.

Fireball 3

This travelled on a slightly diverging track from No. 1, but passing over the western boundary of Coventry. It had an extinction point just south of Nottingham. The fireball had a well-developed yellow tail and left a smoke trail except towards the end of its flight. The quality of the observations of this object was not as high as those of the previous ones, but the few good reports were sufficient to locate the track with a reasonable degree of accuracy. It is assumed that this object was responsible for the reports of flashes in the north-west from some observers at Barwell. In contrast with the other objects, there were no definite reports of a sonic boom attributed to this fireball.

If the calculated tracks of Nos 1 and 3 are produced backwards, they converge on a point near Stow-on-the-Wold, Gloucestershire. The implication that these two objects were the result of the explosion of a single object was confirmed by an observer from Birmingham who witnessed the separation.

Fireball 4

The existence of this object had been suspected for a long time, but the information collected was of such a nature that it was impossible to dismiss other possible explanations. A high-quality report from Bristol indicating that an object had been seen travelling in a NNE direction but passing to the west of Bristol, together with one or two other key observations, put the question beyond doubt. This bolide was reported by several people as being a bluish-green in colour and having a short yellow tail. As with the other objects, some reports were received describing the fireball as shedding sparks and others mentioned a dust trail. The extinction was probably in a position about ten kilometres up but to the west of Nottingham.

With the exception of the divergence of tracks 1 and 2, the tracks of the fireballs were approximately parallel. It is thought likely that they were all products of a single body which broke up initially in the upper regions of the atmosphere. The break-up near Stow, the break-up just prior to extinction of No. 2, and the many reports of sparks falling from the fireballs suggest that fragmentation took place readily. It is possible that the objects described above were only the major fragments of a very complex break-up. This may explain some of the odd reports which had to be rejected because of lack of confirmation. There have been no reports of meteoritic material resulting from any of the fireballs other than fireball 1. It is therefore likely that the other objects were relatively small pieces which were completely or nearly completely destroyed during their passage through the atmosphere. If they did reach the surface of the Earth, the chances of their being discovered are now virtually non-existent.

The Fall at Barwell

The angle of descent of the fragments just prior to landing must have been quite steep. One piece, which penetrated the roof of a factory, descended at about 80° from the south-east. The positions of others were so near to walls and houses that they must have fallen nearly vertically. The actual direction of fall, however, bears no relationship to the direction of flight of the original fireball, because aerodynamic forces can produce quite complex motions on irregularly shaped fragments. They also produce wide ranges in the rate at which the individual pieces fall to the ground. For example, one piece was found lying on the surface and another piece of similar size and falling on to a similar surface was buried to a depth of about twenty inches.

There is no obvious regularity in the size distribution within the fall area, although the very small pieces have only been found within a relatively well defined area in the south-west. This lack of gradation suggests a final break-up late in flight, an idea which is supported by the lack of secondary burning on the surface of the fragments. A study of the fusion crust shows that the bolide did

not rotate during its flight through the atmosphere. Further, the character of the fusion markings indicate that the weight prior to break-up was about 200 lb, indicating that only about half of the meteorite has been found.

The meteorite belongs to the commonest type, known as olivinehypersthene chondrite, a stony variety consisting mainly of magnesium iron silicate with about 8 per cent free nickel iron. The freshly fallen samples looked very similar to newly broken concrete but after the passage of time they took on a brownish colour due to the rusting of the free iron. The meteorite is very brittle and crumbles very easily. Although about 100 lb is suspected to be still lying where it fell, the likelihood of its being found is fairly remote. Even after a few months, there was evidence of erosion, with the sharp edges tending to become rounded.

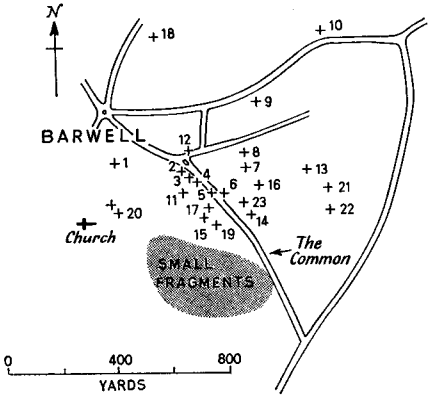


Fig. 2

Figure 2 shows the location of the principal fragments. The area in which small pieces weighing less than an ounce is shown shaded.

1. 4 pieces totalling 3·9 oz
2. 6 lb 4·5 oz – in a hole 9 inches deep in clay
3. 3 lb 11 oz – in a hole 1 ft deep in well dug soil
4. 2 pieces 7 lb 3 oz and 3 lb 14·5 oz

5. Estimated total of 2 lb – fragments on road
6 1 lb – on car bonnet
7. 5 lb 7 oz – on surface on grassland
8. 3 pieces – 14 oz, 4 oz and 1 oz – passed through roof of works
9. 2 pieces 2 lb 9 oz and 7 lb 12 oz – on drive to house.
10. 7 lb 6 oz plus fragments totalling 1 lb 12 oz – on tarmac drive
11. 1 lb 8 oz – on surface by hedge
12. 3 oz
13. 1 lb 9 oz – in hole 3 inches deep in grassland
14. 4 lb 15 oz
15. 17 lb 6 oz – in hole approx 2 ft 6 in deep in grassland
16. 7 lb 14 oz
17. 9 oz
18. 2 pieces totalling 5 lb 14 oz
19. 2 lb 13 oz
20. 2 pieces totalling 1 lb on grassland
21. 1 lb 4 oz – in shallow hole in grassland
22. 15 oz – in shallow hole in grassland
23. 15 oz – in shallow hole in grassland

Although much will be learned from this fall, it is not expected to produce any startling discoveries. Nevertheless, all meteoritic falls must be investigated fully, because at the moment meteorites are the only material from outer space that can be studied in our laboratories. The Barwell fall has certainly aroused considerable interest in scientific circles.

The Progress of Meteoritics in Western Australia and its Implications

G. J. H. McCALL

Western Australia is the largest component State of any sovereign state in the world, its area being approximately one-third of that of the entire United States. Within this vast expanse live less than a million people. These statistics are very relevant to my topic – the progress of meteoritics in the State, because both area and population density are significant controlling factors in respect of meteorite recovery – thus, while the great extent of the State provides an immense reception area for arrivals, the thinness of population militates against any falls being observed.

It is well known that world meteorite distribution is very uneven geographically speaking – for example, no less than 630 of the 1,700 known meteorites in 1961 came from recoveries in the United States, while only six came from China. This overall disparity seems difficult to explain, and there is an additional disparity in observed fall-chance find ratios – for example, the fact that the Indian subcontinent has yielded more than one hundred meteorites, mostly from observed falls, is reasonable in view of the dense population, but, why then the paucity of similar observations from teeming China?

It seems certain that population density and area are two major factors – these controls are, indeed, obvious – yet the case of India and China mentioned above shows that there must be other controls, less obvious. It is strange that it is mainly from China that we have extremely ancient records in ancient writings of meteorite falls: and one may wonder where all these meteorites have gone? One clue may be provided by the known sway over many centuries of war lords, for meteoritic material contains, in all but a few

cases, considerable iron suitable for converting into weaponry. But this cannot be the complete answer.

Looking at disparities elsewhere, two factors, namely *climate* and the *nature of the land surface*, are suggested as major factors. Arid climates have undoubtedly resulted in much meteoritic material lying unusually long on the ground, without decomposition by terrestrial weathering agencies. The numerous recoveries from the great plains of North America must to some extent be related to arid climates, though an almost evangelical drive to recover meteoritic material also contributed. Education of the populace and the presence of an educable populace of some size must also have contributed (and, perhaps, even the commercial impetus of personal gain in the country in which even one's own blood is a commercial commodity?). I shall return to the subject of commerce in meteorites later: meanwhile, let us consider Western Australia in the same context.

In 1962 I commenced advising the Western Australian Museum on meteoritics, being at that time a petrologist almost completely ignorant of meteoritics. Since then I have learnt much about the subject, and one of the aspects that has intrigued me most has been the search for the causes of the abundant recoveries made in Western Australia, and the evaluation of this State's potential for further recoveries. Careful consideration has led me to the belief that the *hard soils* or *hard-pan surfaces* or *gibber-plains* which are predominant in inland terrain, coupled with the *inland aridity of climate*, have made this an optimum territory for meteorite recovery from chance finds – and one particular area, an immense, arid, limestone gibber plain, characterized by thin, barely grassed, hard soil over an irregular surface of limestone poking through everywhere as gibbers (the area we call the Nullarbor Plain extending across into South Australia), one of the most favourable terrains in the world. To counter this, of course, we have little chance of recovery from observed falls, as the statistics show – a single observed fall at Woolgorong in 1960 and nearly seventy chance recoveries.

The aspect of the statistics which marks out Western Australia from other parts of the world is the frequent chance recovery of *stony meteorites*, amongst which one may hope to find the rare types of *chondrites*; and the *achondrites*, all of which are of extreme interest and rarity. While other parts of the world reveal an overwhelming excess of recoveries of stony meteorites from observed falls as against chance finds, the ratio in Western Australia is 23 stony meteorites found by chance against the single observed fall. In addition, several *stony-irons*, all of which, again, are of great rarity, have been found. The stones and the stony-irons tend to decompose rapidly under the influence of terrestrial weathering, and it must surely be on account of the climatic aridity, and consequent lack of vegetation, that such agencies have operated with such extreme slowness in this State. The *iron* meteorites, which are larger and more resistant than the stony meteorites to terrestrial weathering, are also found in considerable numbers; and, if the inhibition of terrestrial weathering is less significant in this case as a preservation factor, the lack of soft deep soil, and vegetation for these large masses to bury themselves in and so get lost, must surely be a real factor.

The collections held in Western Australia, at the Museum in Perth and that at the School of Mines, Kalgoorlie, are not amongst the world's largest – they are small compared with such famous collections as those of the Smithsonian Institution, American Museum of Natural History, the British Museum, and the Calcutta Museum, for instance. But they include several unique meteorites, many rare ones, and many varieties relatively more common (though still of great scientific interest). The material stems from a tally of recoveries nowhere near as numerous as those of the United States, Russia or India, but roughly equivalent to the entire recoveries from the African and South American continents, and in excess of those from China and Canada! These collections must provide a continuing source of valuable material for scientists the world over – for we live not only in the Space Age but also in the Meteoritic Age. Since 1950 the publication of detailed and specialized scientific work of geochemical and geophysical charac-

ter based on meteoritic material has mushroomed to an extent not always fully appreciated, even by scientists. Meteoritics is no longer a pleasant museum curator's backwater; it is part of the mainstream of mid-twentieth century scientific progress.

This brings one to discuss the rôle of our Museum and those who take charge of this aspect of Museum activities. Of course, the great national Museums have immense resources in funds, staff and equipment, and can readily combine descriptive work, cataloguing and advanced, specialized research in geochemical and geophysical fields. But the smaller 'parochial' institution such as ours is not so happily placed. When I entered this field of scientific inquiry four years ago, I realized that, working in an honorary, advisory capacity, for not more than half a day a week, on behalf of an institution possessed of very slender financial resources, sufficient only for administrative requirements, I must set myself severe limitations. The restriction to cataloguing and simple petrographic descriptive work was made voluntarily, after consultation with Dr Brian Mason – one of the world's foremost authorities: and in any case lack of funds prohibits any Icarus-like flight into the exciting world of specialized and advanced geophysical/geochemical studies, except by two of the Honorary Associates of the Museum, who are working in other institutions in the realm of solid-state physics.

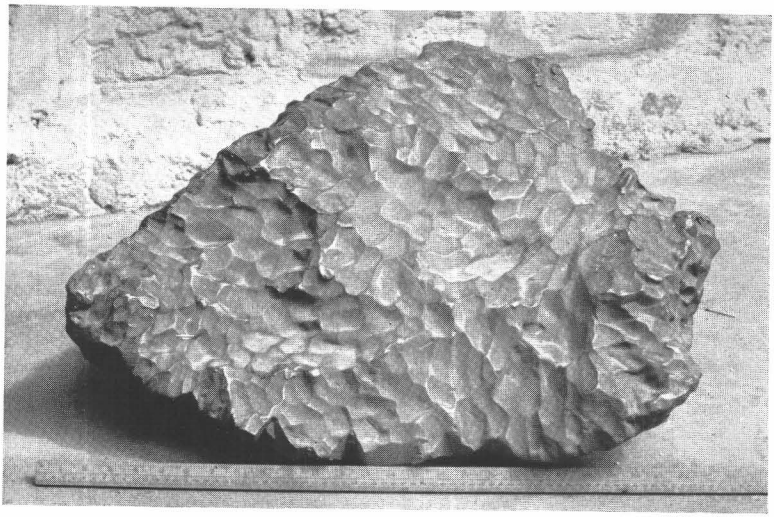
Adopting a restricted programme, we operate by exchanging specimens for analyses, and this has proved quite satisfactory, for we have much to offer. Even if ample funds were available, I would hesitate to change our policy of deliberate restriction. For the truth is that, while in the field of meteoritics more and more sophisticated, specialized instrumental studies are being embarked on the world over, the petrographic basis of meteoritics remains unsatisfactory. Textural information is limited. Mineralogical descriptions still used as a basis for advanced work on long known meteorites are found to refer to augite and anorthite, but the minerals are in actuality nothing of the sort. Classifications similarly referred to are all too frequently those of Brezina, which nowadays appear illogical and afford little more than a physical

description based largely on unimportant characteristics. Though Mason has led the way in redescribing and reclassifying meteorites (his reclassification being founded on the outstanding work of G. T. Prior of the British Museum), there remains much to be done. For example, I could name two well-known stony-iron meteorites from outside Australia which are not anywhere described in anything approaching modern terms.

Science appears at the present time to be suffering from overemphasis of instrumental and computerized techniques to the exclusion of field studies, careful studies by old-established but still valuable petrographic methods, and above all the philosophic approach and consideration of the subject matter in the round, not divorced and isolated from its context. Because of these failings, much advanced instrumental geochemical and geophysical work remains unsatisfactory because, divorced as it is from its context and not satisfactorily related to the whole spectrum of the discipline, there remains uncertainty as to what the results really signify.

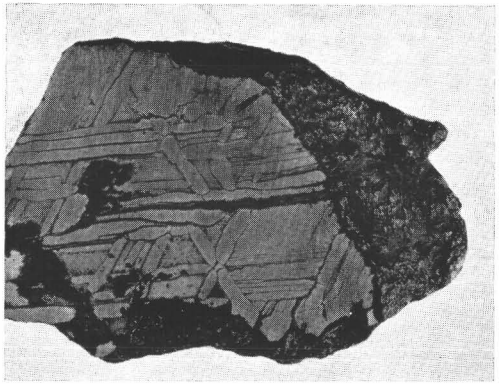
I see the rôle of the petrologist, in relation to lesser Museum collections of meteorites, as primarily one of preparing up-to-date accurate descriptions, in catalogues and scientific papers; of recording physical properties and petrographic properties accurately in modern terms; of securing accurate minerological and analytical data; and also visiting sites of meteorite finds in the field and recording the valuable data of impact pits, fragment scatter, etc. This has been our programme in Western Australia, the main participants being myself and Mr W. H. Cleverly of the school of Mines, Kalgoorlie, who has made a quite outstanding contribution. Over and above this we have the rôle of encouraging new finds by use of publicity media to educate the populace in the importance of this material.

What have we achieved in the past four years? Taking publicization of meteoritics first, results speak for themselves. Meteorites are now coming in from the State at a rate of about five per year, probably a rate not exceeded anywhere else in the world. Most of this material is, I may add, presented by the finders to one or the



3a The Haig Meteorite, a large octahedrite iron from the Nullarbor Plain.

3b The Wolf Creek Crater—$\frac{1}{2}$ mile in internal diameter, it occupies a crater mound, punctuating a vast flat area of semi-desert.



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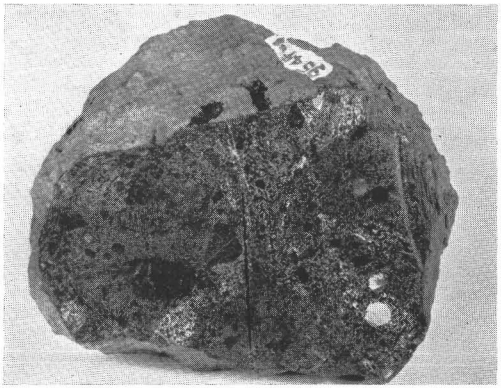

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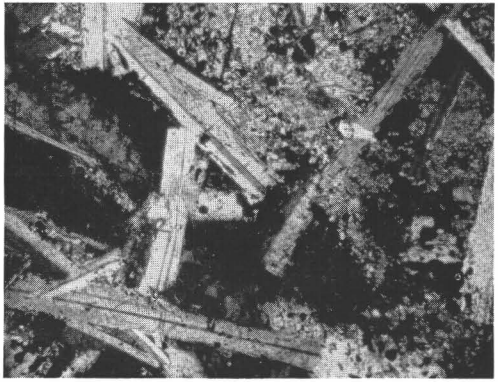

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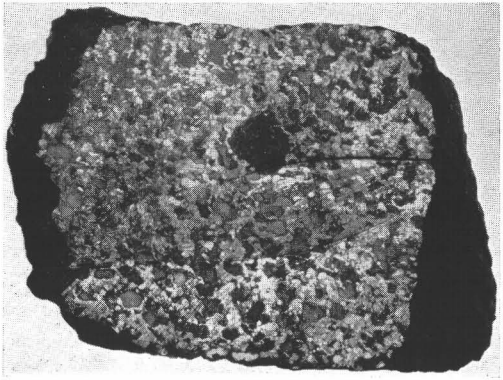


4d

other of the public collections – it is, indeed, only on account of their generosity that I have anything to write about.

Considering the store of meteorites themselves, I can do no more than bring out the highlights. We have prepared a full, illustrated catalogue of the State Collections (Spec. Publ. 3, West. Australian Museum) and already a lengthy supplement is in preparation, so fast does new material come in. After cataloguing, attention could be paid to more detailed investigations and descriptions of the meteorites and craters – both new ones and others long known but so far inadequately recorded.

I mention craters for amongst the most interesting meteoritic occurrences in this State are the two craters and their associated meteorites.

The smaller, the seventy-foot diameter Dalgaranga crater, has been known for thirty years. Dr Nininger suggested, in 1960, that it was formed by a stony-iron, mesosiderite meteorite, and this has been proved by recent microscopic investigation of some hitherto unknown fragments from the crater. It is indeed mesosiderite material, and contains nodules of nickel-iron displaying fine-medium octahedrite etch patterns; also areas of stony material, of the character of the basaltic achondrite type of meteorite known as a 'howardite'. This material displays the sub-ophitic texture familiar to geologists in the common dolerite dyke rocks, and the mineralogy of a terrestrial norite.

It is convenient to mention the Mount Padbury meteorite here, though it has no real connexion with the crater. Discovered in

4a Octahedrite material from near the Wolf Creek Crater (x 1.1).
4b The Mount Padbury mesosiderite meteorite—25 lb mass with cut face showing metal and silicate (achondrite) areas within the stony-iron matrix (width 4·5 inches).
4c Microscope thin section showing basaltic achondrite enclave within the Mount Padbury mesosiderite—material very similar to terrestrial dolerite. Felspar forms laths and pigeonite darker grey grains between them (x 63).
4d The Bencubbin (1) meteorite showing a chondrite enclave within the stony-iron material (x ½).

1964, this is a fragmented mass of mesosiderite material weighing 600 lb – the second largest mesosiderite recovery ever made. It was found a few miles from Dalgaranga, but although superficially similar material, is petrographically quite different. Nickel-iron with fine to medium octahedrite structure forms nodules, and there are also present numerous angular and rounded, abruptly defined silicate enclaves – but in this case not of howardite but of eucrite (a basaltic achondrite type of stony meteorite containing predominantly pigeonite in place of the dominant hypersthene of the howardite), diogenite and olivine achondrite. The latter material is texturally unlike the unique Chassignite and represents a meteorite type not hitherto recognized. The basaltic achondrite material displays a wide range of textures – familiar in terrestrial igneous and metamorphic rocks. The meteorite is in actuality an agglomeration of known and unknown achondrite areas, brecciated and invaded by metal and sulphides. The patchy inhomogeneity is not, however, due to accretion of random meteorite fragments (a process suggested by Urey in another context) but is rather a sample of a patchy internal layer (= 'mantle'?) of a parent asteroid or small planet, reflecting in its patchiness the immiscibility of Goldschmidt's three primary phases, immiscible under all conditions – metal, sulphide and silicate.

The second crater is the Wolf Creek Crater, situated near Hall's Creek in the north-west of the State. Much larger than the Dalgaranga crater, it is a half-scale replica of the famous Cañon Diablo crater, Arizona. Shale balls of volcanic bomb character, and composed of iron-oxide have long been known (and have presented an anomaly), but not until last year was meteoritic iron recovered a few miles from the crater, and recognized as such by scientists at Canberra. This crater is most likely of meteoritic origin – a meteorite explosion crater (Dalgaranga is a fragmentation crater) – but the possibility of endogenous origin, though remote, remains. For firstly, the metal could be derived from another meteorite fall (evidence of 'overprinting' given later in this account shows that this is by no means impossible). Secondly, do we not blindly refer to all nickel iron alloy material which displays Widmanstätten

patterns as 'meteoric iron', yet the known occurrence of similar alloys of terrestrial origin from Disko Island, Greenland, and elsewhere must surely pose the question 'could not some octahedrite material conceivably stem from within our own planet?'

We certainly have valuable evidence for multiplicity of meteorite arrivals in a small area – 'overprinting'. The Nullarbor Plain is the optimum area for meteorite finds in the State, and many of these finds were made by a single family of rabbit trappers. In the Haig-Rawlinna area, near the Trans-Australian Railway line, a group of such finds, of similar stones, first suggested an ellipse of dispersion resultant on a single arrival event. The long axis of this ellipse did, however, seem excessively extended (20–30 miles), and, later, doubts arose. Was this not simply an artifact, the axis of the ellipse being a track up which the trapper operated? This is now known to be correct, for the meteorites now known from the area include several different types of stone – two achondrites, two types of chondrite, and one group of fifty-nine small stones which themselves form an eight hundred-yard long ellipse oblique to the main one. The achondrites include two very dissimilar ureilites (a meteorite type of extreme rarity). Stony meteorites which are observed to fall in showers are invariably of one type – this much is clear from the records. The differences in weathering state support the new interpretation – as a group of overprinted falls.

The Nullarbor Plain must be littered with meteorites of all types – a pallasite stony iron and a large iron have, indeed, been found near this group, and, as I write, news comes of the discovery to the east at Mundrabilla of two immense irons – one, apparently, the largest meteorite ever found in Australia, weighing about 15 tons.

Considering that much of the rest of the State is relatively unexplored, and that arid climates predominate and hardpan surfaces are common; and the fact that the Nullarbor limestone desert has an almost equal extension into South Australia – and considering again the arid wastes of the north of that State and the Northern Territory, the conclusion is inescapable that Australia yet hides a considerable wealth of meteorites lying out on its vast

interior wastes. This material would add much to our knowledge of meteoritics.

We may in passing inquire 'And what of the other continents? What of the deserts of Asia, of the middle east and stony deserts, such as the Gobi (which has lately yielded an immense iron meteorite): of the deserts of Africa such as northern Kenya, the Sudan and Somalia? And the Sahara?' The conclusion is drawn that the search for meteorites, mainly by, in the first place, encouraging reports of new finds in likely areas rather than actual prospecting, has been neglected – perhaps because North America – so profitable once – is to a considerable extent worked out, and given over to commercial exploitation.

The vast store of meteoritic material awaiting to be discovered, outside America, should, I believe, not be allowed to become the subject of commercial exploitation. The value to science is such that it should, ideally, be made State property by the passing of suitable legislation (with, of course, suitable recompense to the finder). We have seen the beginnings of such regulations here in Western Australia, but the present restrictions do not go nearly far enough.

To return briefly to our meteorites: many of our other finds could be mentioned here. I will, however, because space is short, restrict myself to two. Firstly, the unique Bencubbin meteorite, consisting of two masses recovered by the plough. This meteorite, a stony iron, contains patches of chondrite material: a feature not known in any other such meteorite. This material is at present being investigated in more detail than has, hitherto, been done. It promises most interesting results. Secondly, the equally unique Mt Egerton meteorite. This consists largely of inches-long crystals of snow-white, pure, magnesian enstatite, with subordinate nickel-iron of most unusual type (alloyed with silicon). The story of the investigations which led to the rediscovery of this material, first recorded twenty-five years ago and subsequently lost, reads like a detective story: the last chapter was written only a few weeks ago, when, as the result of information given by an aged, nearly blind aboriginal, twenty kilograms of small fragments were found still

lying on the ground at Mt Egerton. The find is interesting, as it shows that there are not only new varieties of known types to be found – there are meteorites of quite new types for which new terms will have to be added to the existing classification. Neither Bencubbin nor Mt Egerton really fit into the existing classification, and the former has already been referred to a new class, the enstatite-olivine stony irons. There must be other such new types lying out undiscovered or still orbiting in space – one of the fascinations of meteoritics is the fact that any day someone may bring in a lump of quite unfamiliar material, a meteorite of extreme rarity or even unique, or, better, one may drop out of the sky: the story of meteoritics can never be complete.

Resisting the temptation to discuss the continued search for the answer to the enigma posed by the tektites, the small glassy 'meteorites' found throughout Southern Australia – and it remains science's most baffling enigma – I conclude by posing one last question:

'Consider, should we not put much more effort (in view of the immense cost of putting a man into Space to obtain a single small lump of the Moon) into finding, describing and utilizing the material that comes to us out of Space, continuously and at no cost; should we not, before it is too late, secure the rich, outstanding store of this material for Museums and Universities and strive to eliminate commercial exploitation for purely personal gain?'

The Hertzsprung-Russell Diagram

R. C. MADDISON

The problem of finding some sort of order in large numbers of vastly different objects, or of finding some simple relationship between them, is one that is familiar to most branches of science. In the mid-nineteenth century, for instance, Mendeléef found himself confronted by a bewildering array of chemicals and reagents having no apparent interrelationship. It was not until he had arranged the elements in the order of their atomic weights that he was able to see a periodicity in their chemical properties that indicated a certain uniformity of atomic structure. This made the whole problem of chemical change much easier to understand. Again, zoologists have found that the study of the whole range of living creatures is made very much easier if certain common properties are used to segregate the creatures into various phyla and species. A comparison of the sub-divisions that arose out of this simple classification led to an awareness of evolutionary processes that are impossible to observe directly because of the gigantic time-scale involved.

Astronomers are faced with an equally bewildering problem when they look at the stars and attempt to make generalizations about their structures and properties. Consider, for example, the brightnesses of the stars. In order to make any sort of comparison it is first necessary to eliminate the effects of the varying distances of the stars, and this can be done if we imagine each of them to be at the same distance from us. A comparison of the brightnesses as we then see them will represent a comparison of the 'real' brightnesses or the actual radiant energies of these stars. The standard distance is traditionally chosen to be 10 parsecs (32·6 light-years); the power output calculated for this distance is called

the intrinsic brightness and is known quantitatively as the absolute magnitude.

The astounding outcome of this stellar line-up is that the range in power output between the brightest and the faintest stars is more than a million million. It is impossible to appreciate what this figure means, but some impression may be obtained if we look at it another way. We may represent the faintest star by a small dot on a piece of paper only a millimetre in diameter, and if the diameter of the dot indicates the intrinsic brightness of the star, then we should find that for the brightest star we should need a piece of paper five hundred thousand miles across – greater than the entire orbit of the Moon around the Earth!

If, for contrast, we measure the masses of these same stars we find that the complete range is only one thousand-millionth of the brightness range. In other words the most massive star known contains just one thousand times as much material as the least massive. The fact that there is such a big difference between these ranges shows that we must be looking at a fair cross-section of stellar age groups and that there must be differences in radiating power and energy production in the stars. The reasons for these conclusions are simple. The main source of energy in stars is the thermo-nuclear fusion of hydrogen atoms to form helium, with the consequent conversion of matter into radiation, and these reactions take place in stellar interiors at temperatures up to twenty million degrees. The resulting energy diffuses through the stellar material and is radiated away from the surface at a much lower temperature. Other fusion reactions leading to the production of heavier elements require higher internal temperatures, and the stars using them will generally have hotter radiating surfaces. Very bright stars will naturally be radiating their energy much faster than faint stars and they will be using their nuclear fuel at a rate that will seriously limit their lifetimes; obviously a star will cease to shine when it has used up all its fuel. Faint stars radiate comparatively slowly for a much longer period, and so, when we look at all the stars distributed around us, and we see a mixture of very bright and very faint ones, the chances are that we are looking at some very young bright stars and some

very o d faint ones. This assumes, of course, that many stellar generations are present in various stages of their life cycles.

The rate of energy radiation from a surface depends on the fourth power of the temperature of the surface, and this relationship, which is known as Stefan's Law, tells us that we would expect the very bright stars to have higher surface temperatures than the faint ones. This would also seem to imply that the stars having high surface temperatures are likely to be the young ones.

Stefan's Law can also be used to extract information on the relative sizes of the stars. The statement that the energy radiated from a surface is proportional to the fourth power of its temperature refers to a fixed area of the surface. The constant of proportionality for the relationship is a well-known quantity, and is usually measured for unit area of surface.

If the absolute magnitude of a star can be found from its apparent magnitude and its distance, then it is a relatively easy task to calculate the total amount of energy being radiated by the whole star. If this figure is related to the surface temperature of the star by Stefan's Law, then an estimate may be made of the total surface area of the star, and this is an excellent method of estimating stellar radii.

Although the mass and brightness ranges of the stars are so widely different there is a direct relationship between them which applies to the great majority of stars. In 1924 Eddington discovered what is now known as the mass-luminosity relationship when he plotted the absolute magnitudes of the stars against their masses. Nearly all the stars fell on a smooth curve, which showed that the brightest stars are generally the heaviest and the faintest stars the lightest. This sort of relationship can be constructed intuitively by imagining the equilibrium conditions that probably prevail inside most stars. A small volume of gas and dust, collapsing upon itself under its own gravitational field, will reach equilibrium when the pressure of the thermo-nuclear radiation balances the gravitational pressure due to its mass. The resulting star will be small and will have a certain brightness. A large mass of the same condensing material will generate a correspondingly higher gravitational pres-

sure which, in turn, will require a greater radiation pressure for balance. In this case the star will be larger and brighter. This grossly simplified picture implies a mass-brightness relationship that should apply to stars of basically the same chemical constitution.

We can see from the preceding brief survey that there are a few relationships between the widely differing properties of the stars that allow us to make some guarded generalizations about their behaviour. Probably the most interesting relationship, however, was described independently by the Danish astronomer Ejnar Hertzsprung and the American astronomer Henry Norris Russell when they published the results of their work on the correlation between the absolute brightnesses of the stars and their spectral types in the year 1913. The sorting of the stars into the spectral types O, B, A, F, G, K, and M is done by a comparison of the relative intensities of certain lines in the spectra and an ordering of the spectra so that there appears to be a smooth graduation from one to the next. It was shown in 1920 by M. N. Saha that this classification is actually one of temperature, and that the range from type O to type M is a range of surface temperatures running from about fifty thousand degrees down to about three thousand degrees.

The original 'absolute magnitude-spectral type' diagrams are called Hertzsprung-Russell diagrams after their inventors, but the 'temperature-magnitude', and 'colour-magnitude' diagrams often referred to in texts are representations of the same basic relationship.

The mass-luminosity relation was not known when this work was done, and the stars were thought to exist in all colours at all brightnesses. It was therefore quite surprising when the first H-R diagram revealed a well-defined pattern in the distribution of colours with brightnesses.

The first diagrams could be drawn only for those stars near enough to the Sun to have had their distances measured with a fair degree of accuracy, and bright enough to have had their light analysed spectrographically. For the very faint stars whose spectra

were not available it was possible to obtain a rough estimate of the surface temperatures by comparing the visible and photographic apparent magnitudes. If the stars can be considered to be perfect energy radiators then, according to Wien's Law describing the distribution of radiant energy along the spectrum for various

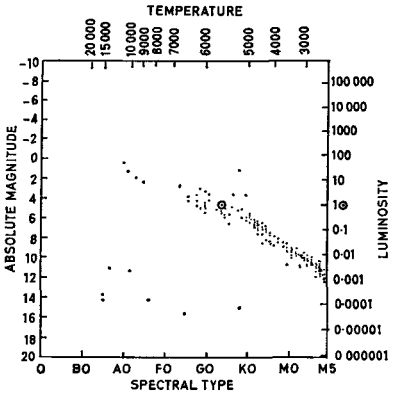


Fig. 1. The Hertzsprung-Russell diagram for all the stars within a radius of 30 light-years of the Sun. (The small circle represents the position of the Sun.)

temperatures, the colour for maximum energy can be used as a measure of the stellar surface temperatures. A very hot star, for example, will appear bluish and will have a greater photographic magnitude than visible magnitude, whereas a cooler star will be redder and have a greater visible magnitude. This method has now been refined and improved so that colour indices can be measured unambiguously using filters covering the extreme ends of the entire spectrum.

The H-R diagram for all the stars within a radius of 30 light-years of the Sun is shown in Figure 1. (It should be noted that the absolute magnitudes are plotted as ordinates, but that the temperatures, or spectral types, are plotted as abscissæ in the unconventional sense, i.e. with values decreasing towards the right. This is done simply because the early diagrams were presented in

this way, and there seems to be little reason for changing a good system.)

Nearly all the stars lie on a diagonal running from the centre of the picture to the bottom right, and this is precisely what would be expected from the mass-luminosity relation. The rest of the diagram seems to be bare except for a handful of points scattered over the lower left corner. These white stars, of spectral types B, A and F, are very faint compared with the stars of the same types on the diagonal, or 'main-sequence' as it is usually called, and it follows from the laws of radiation that they must have small surface areas and be physical dwarfs of the order of only one-hundredth the size of our own sun. If the measurements are extended to include most of the stars whose absolute magnitudes have been determined, then the whole H-R diagram seems to be extended upwards to greater absolute magnitudes. (Figure 2.) The main sequence then extends from corner to corner, and there is a group of cool but very bright stars, high at the right of the diagram, that must be in reality a group of giants each one more than a thousand times greater than our sun. It is not possible to represent the population densities of the various parts of the diagram accurately by means of dots, because the main sequence would have to be blacker than black. The density spread is estimated to be about one per cent dwarfs, rather less than one-hundredth of a per cent giants, and about one hundred-thousandth of a per cent in a small class of supergiants. All the remaining stars belong to the main sequence. Although there are a few members of the supergiant class in Figure 2, the representation is somewhat distorted because such very bright stars can be measured at distances that overwhelm great numbers of main sequence and white dwarf stars.

It is obvious that the stars must undergo some evolutionary change, because the various nuclear fuels will eventually become exhausted leaving hot spheres of gas, having 'no visible means of support', which must sooner or later collapse upon themselves under their own weight. All such changes will affect the temperature and brightness conditions at the stellar surfaces, and these will determine the positions of points on our H-R diagram. The

diagram can now be seen as a fundamental guide to the time-scales involved in the evolution of the stars, since it represents a statistical picture of the state of the stellar population at a particular instant of time. We must again assume that the cycle of births and deaths among the stars has been continuing uniformly for a very long

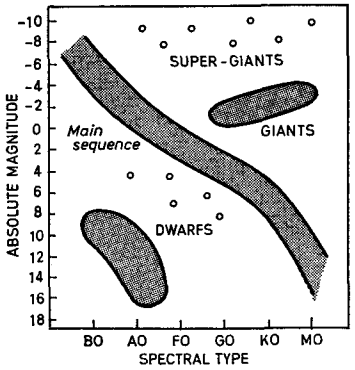


Fig. 2. Schematic H-R diagram for all stars

time and that the relative proportions of the various age groups have reached equilibrium. If this is the case, then the relative population densities must reflect the relative lengths of time that the stars spend in each phase of their lives. The fact that the dwarf and giant parts of the diagram are sparsely populated leads us to believe that these phases of stellar life are short compared with the main sequence, and it follows that we are more likely to find middle aged adult stars in the main sequence, where they will be spending the greater part of their active lives.

Further evidence for this can be obtained from a theoretical consideration of the processes taking place in stellar interiors. It is probable that stars are born when clouds of gas and dust contract upon themselves under their own gravitational attraction and begin to heat up at the expense of the energy of the gravitational field. Such young stars will be cool, but will increase in temperature as the gravitational collapse continues, and they will

first appear at the extreme right of our H-R diagram. Eventually the internal temperature will be sufficient to ignite the hydrogen-burning nuclear reaction, and at this stage the star will have arrived at the main sequence. Its position on the main sequence will be controlled by the mass-luminosity relation and will therefore

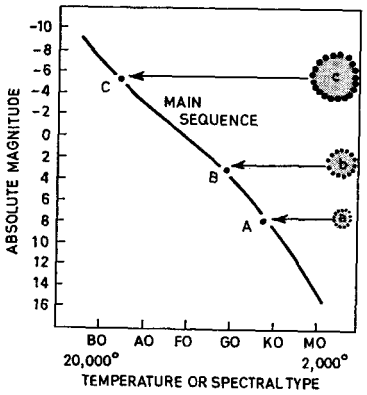


Fig. 3. Some possible condensation tracks

(*a*) to (*A*) Small gas cloud condensing to form a star at *A* on the main sequence

(*c*) to (*C*) Massive gas cloud forming a star at *C* on the main sequence

A, *B*, and *C* represent points of increasing mass whose brightnesses are determined by the mass luminosity relation.

depend on the size of the original gas cloud. (Some possible condensation tracks are shown in Figure 3.) This first stage in the life of a star will be fairly rapid, and we may not be able to find more than one or two stars in our immediate neighbourhood that are actually passing through the phase. Once a star has arrived at the main sequence it is unlikely to evolve along it since this would require substantial increases or decreases in its mass. The main sequence must be regarded as a band on the diagram that links the possible positions of newly-developed adult stars of differing masses, and it represents a projection of the mass-luminosity relation as a series of points, and not as an evolutionary track. It has been estimated that stars spend about a thousand times

longer in the main sequence than in the preceding condensing phase. For faint stars this can mean a main sequence lifetime as long as 10,000 million years, but for bright stars, using their fuel more extravagantly, the lifetimes may be as short as ten million years.

It is believed that the inside of a star behaves as if it were constructed of a series of concentric shells, and that there is very little interchange of material between the separate layers. Nuclear fusion commences at the centre of the star, where the temperature may be several millions of degrees, and the star begins its career as a member of the main sequence. At the end of this prolonged second stage of its life, the star has used about 10 per cent of its available hydrogen and the concentration of helium 'ash' begins to have a significant damping effect on the nuclear reactions. This eventually causes the reacting core to expand into the next outer shell in search of more fuel. In consequence a slowly expanding central core is formed that increases in total brightness and pushes the outermost layers of the star to even greater distances from the centre. At this stage much more energy is being released in the reacting region and subsequently radiated from the stellar surface. The expansion, however, causes a cooling of the outer layers, and the overall result is one of increased radiation from a cooler but much larger body. The changes in brightness and colour, which are caused by the expansion, alter the position of the star on the H-R diagram so that it appears to evolve away from the main sequence and move in the general direction of the top right corner of the diagram, towards the domain of the red giants. (See Figure 4.) After some time the hydrogen supply will have been depleted to such an extent that the radiation is no longer able to support the star in its highly distended state, and further gravitational collapse takes over. This causes a drop in brightness, and a great increase in internal temperature, that is adequate to start the next stages of fusion, involving helium and higher elements. The corresponding evolutionary track on the H-R diagram moves from the red giant stage downwards and to the left until it crosses the main sequence much higher than the original point of condensation. (See section (*C*) of Figure 4.)

Once all its nuclear fuel has been exhausted, the only remaining source of energy that the star can draw upon is the energy of its own gravitational field. It does this by again collapsing upon itself and converting the remaining potential energy of its material into heat. The result is obvious – the star gets smaller and smaller and

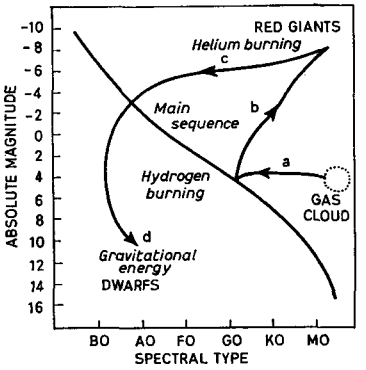


Fig. 4. Evolutionary track for a typical main sequence star

A. Condensation
B. Expansion to red giant stage
C. Gravitational collapse after helium exhausted
D. Cooling into insignificance

eventually begins to cool into insignificance. The physical state of these dying super-dense stars is difficult to imagine, because all sense of atomic structure has been squeezed out of them until they exist in the form of 'degenerate material' consisting of closely packed atomic nuclei. It is very difficult to say anything about any subsequent life that a star might have, because it will probably have ceased to radiate, but we can depict this last stage on our diagram by a point near the temperature axis representing a star that is too faint to observe.

This highly simplified and qualitative picture of stellar evolution gives us some idea of what we might expect to find on the H-R diagram for all stars providing that they all have the same

basic constituents and that young and old are existing together in an equilibrium of life and death.

Stellar populations like this do exist; in fact the solar neighbourhood is a region where new stars are continually condensing from the inter-stellar medium. The types of stars present in regions like this are called population I stars.

This is not always the case, however, for there are stars having different distributions in regions of space that appear to be devoid of gas and dust clouds; these are called population II stars. The main difference between these two distributions is that the population II regions are deficient in the bright blue stars normally found at the top left end of the main sequence. Instead there seems to be a greater density of giant and dwarf stars. This seems to indicate that the population II regions are older regions where most of the available gas and dust has already been incorporated into stellar interiors. Under these conditions new stars would not be able to form, and the life and death equilibrium would be disturbed. The rapidly evolving massive blue stars of the main sequence would then be reduced in numbers after a relatively short time. It seems that in general the population I stars are concentrated in the spiral arms of the Galaxy and in the associated galactic clusters, and that the population II stars are to be found at the centre of the Galaxy and in the globular clusters.

So far I have described results that have been found to apply to the stars in general when all age groups are present at the same time, and I have mentioned that certain broad differences are apparent between regions of the Galaxy that seem to be of different ages. If we now restrict our observations to those stars whose ages we know, so that we can arrange them in chronological order, then we should be able to obtain much more information on the directions of stellar evolution. Unfortunately we are unable to do this, because we have no means of finding the exact ages of the stars, but we can do the next best thing in that we can select stars that have approximately the same ages. When we look at galactic or globular clusters we are looking at families of stars that all condensed out of the same huge cloud of gas at roughly the same

epoch. Different clusters will have different ages, and if we plot separate H-R diagrams for each cluster we will find that they will all be at different stages of evolution. A single cluster will contain both heavy and light stars that were initially distributed along the

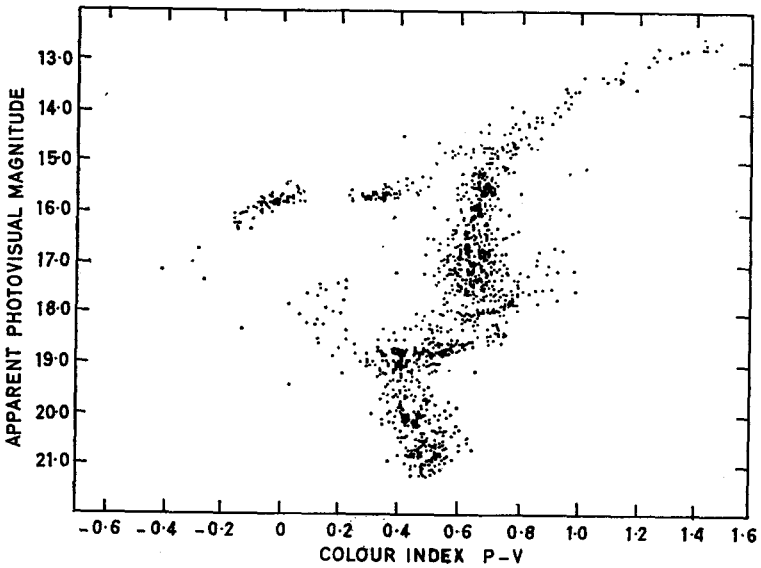


Fig. 5. Colour-magnitude diagram for the Globular Cluster M3
(Diagram by H. C. Arp, W. Baum and A. R. Sandage)

main sequence in accordance with the mass-luminosity relation. The very bright stars will have been using their fuel very fast but for roughly the same length of time as the slowly-reacting faint stars. In other words, the bright stars will have evolved further than the faint stars, and an 'evolutionary spectrum' or 'time-line' will emerge that will show the changes that the main sequence stars undergo at various stages of their lives. Figure 5 is the H-R diagram for the globular cluster M3, and it shows quite clearly that the cluster is of such an age that most of the hot main sequence stars

have evolved right across to the red giant stage, and that some of them are on their way back to become dwarfs. The points at which stars seem to be turning off the main sequence is a guide to the age of the cluster, in that the stars at that point will just be commencing the expansion phase of their lives.

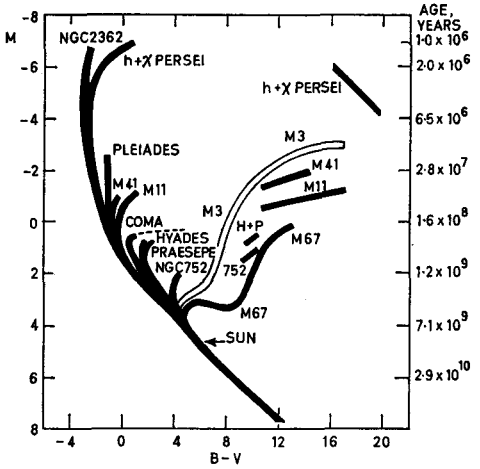


Fig. 6. Composite of H-R diagrams (colour-magnitude diagrams), for ten galactic clusters and the Globular Cluster M3
(Diagram by Allan R. Sandage)

Figure 6 is a composite of the H-R diagrams of several clusters, and their various ages can be reckoned from the spread in the positions of the main sequence turn-off points. Obviously, for example, the Pleiades cluster is very much younger than M67.

I have attempted, in these few pages, to describe the ways in which the lifetimes of the stars have been investigated although it is only possible for us to see them at a particular instant of time. The problem is very like the one of trying to work out the life cycle of homo-sapiens from a single photograph of a large crowd of people and perhaps a handful of photographs of schoolmates and other groups of contemporaries.

There has been a certain amount of success in constructing relationships and diagrams, and in building a picture of stellar evolution, but the next few years should see substantial additions to our information as we become better equipped to observe the sky in hitherto unexplored regions of the electromagnetic spectrum.

Interstellar Dust

IAIN NICOLSON

The space between the stars is far from being the totally empty void it was once thought to be – in fact it is now known that interstellar space is filled with a tenous mixture of gas and minute solid particles. The Galaxy, of which our sun is a very ordinary member, consists of something of the order of a hundred thousand million stars (10^{11}), and of the total mass of our Galaxy, between one and ten per cent consists of the interstellar matter. As this amount of material is spread out over the whole volume of the Galaxy it is hardly surprising that its mean density is very low indeed – only about one atom per 10 cubic centimetres; even at its densest there are only some hundred atoms to a cubic centimetre – corresponding to a very good terrestrial vacuum! A study of this matter is of great importance with regard to understanding the structure, nature and evolution of our own Galaxy and all the other galaxies.

The subject of interstellar material is a vast one; in this article we shall only discuss in detail the solid 'dust' particles as distinct from the atoms, molecules, and ions which make up the interstellar gas.

The presence of dark patches in the starry background of the Milky Way, some of these patches being clearly visible to the naked eye, has been known to many generations of astronomers. Even although no less a person than Sir William Herschel said that these patches were holes in the heavens, devoid of stars, the notion that there should be holes through the myriads of stars, radiating spoke-wise from the Solar System, is completely untenable. The explanation lies in the presence of clouds of obscuring matter lying between us and the background stars – this material being, in fact, small particles which scatter and absorb light from the

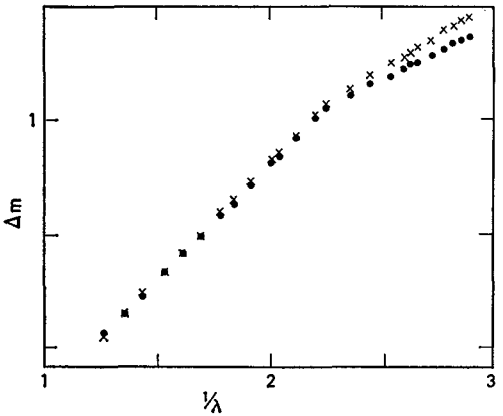
stars. As was mentioned earlier, the density of interstellar dust is extremely low; but when we consider the diminution in intensity of the Sun's light produced by a small terrestrial cloud or a column of smoke, it is easy to appreciate how these minute dust grains spread out over vast volumes of space can diminish or block out the light from distant stars.

The presence of dust also explains one class of luminous nebulæ – namely the reflection nebulæ. There are two main types of bright nebulæ visible in the sky. The nebulæ surrounding very hot luminous stars shine mainly by absorbing light from these stars and re-emitting it, the spectra of these, the 'emission nebulæ', showing characteristic lines distinct from the spectral lines of the accompanying stars. The spectra of reflection nebulæ, however, are closely similar to those of the near-by stars, stars which are too cool to excite the gaseous material to re-emit light. These nebulæ shine simply by the reflection of light from the dust particles, much as fog is illuminated by car headlamps. It is important to note, however, that this does not mean that the emission nebulæ consist only of gas and the reflection nebulæ only of dust: the two have basically the same content (a mixture of gas and dust), but only with very hot stars will the absorption and re-emission process be effective.

The Reddening Effect

The most important observational result concerning the dust is the reddening effect. This effect makes itself plain in everyday experience in the form of a red sunset, where the Sun's rays passing through the dust in the Earth's atmosphere are diminished in intensity in such a way that light with a shorter wavelength (blue) is affected much more than light of a longer wavelength (red). In consequence, red is accentuated. The same sort of thing happens to starlight in its passage through interstellar dust – short-wave light is absorbed and scattered much more than long-wave light; in fact, the longer the wavelength, the less the extinction of light. If 'extinction' is thought of as absorption and scattering combined, for any wavelength λ the extinction varies as $1/\lambda$.

This $1/\lambda$ law is of great importance. It implies that the absorbing matter must be small particles of material – individual atoms and molecules cannot produce such an extinction law. Over most of the visible range of the spectrum the $1/\lambda$ law holds almost exactly, indicating that the particles must be of similar size to the wave-



Interstellar extinction curve in the direction of Cygnus and Perseus. Crosses denote Cygnus results and filled circles results for Perseus. Note the much sharper change in slope for the Perseus results. Observations by K. Nandy at the Royal Observatory, Edinburgh.

$\triangle$ m = the change in magnitude produced by absorption
$1/\lambda$ = the reciprocal of the wavelength in units of micron^{-1} (μ^{-1}); i.e. here $1\mu^{-1}$ = 10,000 Ångströms, $3\mu^{-1}$ = 3,300 Ångströms

length of visible light, i.e. of the order of 10^{-5} centimetres in diameter. The behaviour of the reddening curve at longer (infra-red) and at shorter (ultra-violet) wavelengths indicates that the grains are all similar in size. Needless to say, knowledge of the size and variation in size of the particles is of considerable importance to theories of their nature and origin.

The exact shape of the reddening curve is required to an exceedingly high degree of accuracy, and a great deal of current observational research on interstellar dust is being devoted to the

determination of this and of any variations in the extinction curve in different regions of the sky. The observations are far from easy; due to the low density of material, observed stars must be very far away in order that the reddening be appreciable. (The extinction in general is of the order of 1 stellar magnitude per kiloparsec – 3,260 light years.) There must be comparison stars which are unreddened (or very nearly so), and of exactly the same spectral type as the reddened stars whose spectra are to be compared. The intensity of the spectrum of each reddened star is compared at a large number of points with the intensities at these points of the spectra of several unreddened stars, and the reddening curve drawn up from these measures. The curve has now been very accurately measured over the visible range of wavelengths, but observations are hampered by the fact that the atmosphere prevents light of wavelengths outside this range from being detected. However, a few observations made by equipment carried in a rocket have helped to extend the curve into regions which may be critical in deciding between theories of the grains. A further interesting point is that Nandy's work has shown that the reddening curve is not a smooth curve (which is easier to produce theoretically) but consists in the main of a straight line with a pronounced change of slope at 4,300 Ångströms (one Ångström is equal to 10^{-8} centimetres). This change of slope varies from region to region of the Galaxy; it would seem, then, that the grains have different properties in different parts of the Galaxy.

Polarization

Besides the reddening results, useful information may be gained from the polarization of starlight. Broadly speaking, light waves can be considered as vibrating in all directions perpendicular to the direction in which the beam is travelling: when light vibrates in one direction only, it is said to be plane polarized, the direction in question being the plane of polarization. This polarization effect is observed in starlight, and a definite correlation between this and the reddening effect has been established – wherever there is polarization, there is also reddening. This polarization can be

explained if the grains are asymmetrical and aligned in some fashion, probably by magnetic fields.

Any theory of the grains must be able to account for the observed polarization as well as the reddening curve. At the present time there are three main theories of the grains.

First, there is the dielectric grain model, or – as it is often known – the 'dirty ice' model, first proposed by Van de Hulst. He considers that the grains grow from the interstellar gas by accretion, the major constituent of the particles being water (since hydrogen and oxygen are readily available). There will, of course, be other materials as well – hence 'dirty ice'. Difficulties arise in explaining exactly how the nuclei for the particles will form, and also in finding a suitable process to prevent accretion continuing beyond the required size of particle. To explain the polarization results, it is essential that the particles are not symmetrical – a situation which ought not to arise by random accretion. A possible explanation may be that collisions between grains cause them to adhere and fuse together into elongated particles.

A second theory, due to Platt, is also an accretion process concerned with the formation of large free radicals within the interstellar gas. The theory has not yet been worked out in sufficient detail for many observed effects to be predicted, and little more can be said at this stage.

The third theory, worked out principally by Hoyle and Wickramasinghe, is that the dust consists basically of graphite grains, possibly with mantles of ice. The theory of formation of graphite grains has been worked out in some detail, and is rather interesting. It is thought that graphite grains will be formed in the atmospheres of cool C (Carbon) stars – stars which contain more carbon than oxygen. In particular, the N-type large radii stars which pulsate would be most suitable, graphite grains being formed as the star cools from its maximum phase and being blown out from the stars by radiation pressure. It is estimated that there are sufficient N stars in the galaxy to produce enough graphite grains to account for the observed amount of obscuration.

Hydrogen, oxygen, and other materials will readily adhere to

graphite, and by combination, ice ought to form on the surface of the graphite grains. The differing reddening curves are explained by assuming that in some regions the particles consist of graphite and ice, while in other regions the particles consist of graphite alone. This presents a difficulty; but it is interesting to note, however, that in one of the regions studied by Nandy (Perseus) there has been discovered a very large group of very hot O-type stars. It may be that the radiation from these stars would be sufficient to evaporate the ice mantles from grains in this region. It is possible on the graphite theory to explain the change in slope of the reddening curve, and – due to the structure of graphite and its inherent properties – the polarization effects can be readily explained. Needless to say, the situation is not quite as simple as I have made out, but it does seem as though the observations and theoretical problems can best be accounted for by some sort of graphite grain theory. However, the study of the interstellar medium is in such a state of flux at present that it would be unwise to make any categorical statements.

The importance of the grains cannot be over-emphasized. From the purely negative aspect, the dust absorbs and distorts light from distant stars, causing them to appear fainter than they ought, and thereby leading to false estimates of distance. In fact, the dimensions of the Galaxy have been over-estimated in the past for this very reason. When it is remembered that the amount of absorption varies from region to region, then the determination of distance becomes a very involved problem indeed! The dust is confined to the plane of the Galaxy and completely obscures the centre of the Galaxy from direct view (although radio observations are little affected). On the other hand, the grains can be used as tracers of the galactic magnetic field, and it is thought that they may play an important rôle as a catalyst in the formation of molecules in interstellar space, and are involved in the formation of new stars.

At any rate, they are of considerable interest, and research is being pursued in many centres into their nature and properties.

For this reason, developments are rapid and a great deal may have happened by the time that this appears in print. At the present time, though, it does look as though the interstellar dust may be little more than 'celestial soot' poured out into the Galaxy by carbon – rich stars smoking their way through space!

Spiral Structure in Galaxies

P. A. WAYMAN

Among the most striking, and indeed beautiful, photographs of astronomical objects are those of spiral galaxies. Spiral structure in nebulous objects was discovered visually with the cumbersome 72-inch speculum reflector of the third Earl of Rosse in Ireland around 1850, but it was not until long-exposure photographs taken with the first of the great Mount Wilson telescopes showed the existence of a multitude of faint spiral nebulæ that the possible significance of spiral structure in the overall picture of stellar formation became apparent. It gradually became clear that the spirals were to be classified, along with the more regular elliptical nebulæ, as stellar systems outside our own galaxy or Milky Way system, and roughly equivalent to it. The work especially of Hubble in the 1920s and early 1930s on the extragalactic systems, and of Shapley on our own galactic system established the correctness of this view and led to an immense expansion in the space that could be visualized as being occupied by observable objects. Exploration of the universe, however, is carried out not only with large astronomical instruments, but depends very considerably on the cohesion of ideas provided by some degree of mathematical representation, in physical theories designed to constitute an acceptable framework in which the observations are to be fitted. Thus one of the most important features in the development of our knowledge of the extragalactic objects has been the framework of possible models of the universe provided by the general theory of relativity. The combined discoveries represented, over a period of forty years from the beginning of the twentieth century, a notable 'revolution' in man's regard of the universe. If the intriguing spiral shapes had not been there, but only elliptical nebulæ, this step might have been much delayed.

In recent years the discoveries of radio astronomy, coupled with

optical information on objects emitting radio waves strongly, have provided us with the prospect of proceeding in more than speculative fashion to a further stage. New types of energetic extragalactic objects have been discovered, and we can consider the possibility of describing the whole sequence of changes that stellar systems undergo. Essential to this next step is the thorough understanding of the processes that affect the development of individual stars. That is, we must be able to describe how stellar formation can take place and go on taking place, what happens to the composition of stars as they grow old, and such questions as whether the stellar material is subsequently redispersed. To cover this 'inner' story comprehensively must remain an incomplete task for a long time to come, but, thanks to the contributions from nuclear physics and from the availability of electronic computers, much has already been achieved. The structure and life-history of normal stars is, in all probability, correctly understood in outline and processes of stellar formation, causes of variability, and ejection-mechanisms, are gradually being brought within the boundaries of general acceptance. The processes of organization into stellar systems lies intermediate between these processes and those relevant to the structure of the universe on a very large scale. Why the galaxies occur in the multiplicity of forms that they do, what is the full significance of spiral structure, and the general evolutionary pattern of galaxies remain unresolved questions towards which we can expect considerable progress in the forthcoming decades.

It is the main purpose of this account to consider the situation of spiral structure. It is certainly a striking phenomenon, but it is as well to say at the outset that it is by no means thoroughly understood, and it may not be particularly fundamental to the evolution of stellar systems.

The bright blue stars at the top end of the main sequence in the Hertzsprung-Russell diagram are up to twenty times the mass of the sun. But such massive blue stars are expending their internal energy at a rate 10,000 times as great. Consequently, although solar-type stars can be shown to have enough available energy to last them 10,000 million years or more, the expected lifetime of the

largest blue giants is only around a million years. Therefore, these prodigious radiators of energy must be essentially 'young' objects. That they are prodigious radiators means that the regions where they are situated are particularly noticeable in the pattern obtained in photographing the galaxies, and the mass-distribution within these galaxies is not necessarily as indicated by the light-sources. Furthermore, since the blue giants are essentially young objects their distribution is linked closely to the distribution of interstellar material from which it is envisaged the stars are constantly forming. Thus galaxies without much interstellar gas and dust do not contain blue giants, and in those galaxies containing gas and dust the blue giants are located only in those regions occupied by the gas and dust. In the larger systems the gas and dust has often attained a distribution approximating a thin flat rotating disk, while much of the material already formed into stars is distributed in a more spherical shape. Some idea of the way in which this might have happened can be described in the following manner.

If we imagine the contraction under its own gravitation of a large amount (galactic mass) of hydrogen, the relative motions of this material will result in mutual collisions of the denser condensations, partially dissipating their energy of motion. Some stars will be forming all the time, and once formed into such a tight concentration as a star the motion of this material will be largely unaffected by collisions. Apparently much of this earlier stellar formation took place so as to form clusters of stars and these remain as the globular clusters, travelling around the centre of the galaxy, generally in fairly elliptical orbits and at random orientations. Even though the nuclei of globular clusters appear to be dense, a globular cluster can still pass through the galactic disk relatively unscathed. The material which remained in the form of gas clouds retained its overall angular momentum but the processes of contraction, energy dissipation, and momentum exchange within the total mass continued until, hypothetically, it reached a state of motion, consistent with its total angular momentum about the centre, in which the occurrence of mutual collisions was much reduced. There appear to be two possible shapes satisfying such a condition. One

is an ellipsoidal distribution with three strongly unequal axes, rotating about the shortest of the three axes rigidly. The other is a thin flat disk rotating about its centre, the rotation not being rigid but reducing in angular velocity about the centre outwards. In the latter case circularity in the motions of the individual clouds is gradually attained; stellar formation goes on taking place, and the new young 'open' clusters so formed are, since they are constantly passing through or close to other clusters and large gas clouds, disrupted by tidal influences. The tidal influences of the gravitational field of the whole mass also contributes to this disruption. It is in this state that the tendency to develop spiral structure must occur.

The settling-down to a steady differential motion in a thin flat disk is similar to what happened on a much smaller scale to the fragmented satellites that form Saturn's rings. An analogy to this process is the everyday phenomenon of water in a bucket which, however it is poured in or agitated, will after a short while settle down to the form of quasi-steady differential rotation. Under the containing forces of a central gravitational field the form takes the shape of a flat disk and the gravitational field just above or below the disk is rather in a direction of attraction back towards the disk than towards the centre of the galaxy. The way in which this flatness is achieved depends upon there being, at any rate in the early stages, a considerable interchange between objects at substantially different radii. The gas clouds and stars which form at the present time the major part of our own flattened disk do not now vary their distances from the centre by more than about ten per cent. In the outer regions there are measurable deviations from flatness in the gas layer, but it is thought that these have probably arisen subsequently, through tidal encounters with other galaxies. In order to make use of detailed information from within our own Galaxy we should first examine how well it fits in with the spiral structure observed in other galaxies.

It is well-known, in Hubble's system of classification of spiral forms, that as well as the elliptical galaxies there are two sequences of spiral forms, the 'normal' spirals and the 'barred' spirals. Start-

ing from the end of the sequences where they divide from the elliptical galaxies, the spiral arms become progressively more open and clearly-delineated, and the central masses become relatively smaller. de Vaucouleurs proposes more elaborate classification in a three-dimensional scheme, in which greater attention is paid to the nature of the spiral form; for instance, whether the bar is pronounced or not, or whether a ring-formation occurs. To encompass such a wide variety of forms under the general nomenclature of 'spiral structure' and seek a single explanation is unlikely to be successful. Thus the frequent occurrence of a bar-like structure is certainly accompanied by rigidity, but this rigidity does not appear to exist, for instance, in the corresponding regions of our own Galaxy. Again, many of the spirals show a degree of symmetry across the centre. That is, there are two principal arms winding similarly on opposite sides. This symmetry is never complete; it is often barely detected, there being additional fragmentary arms, and sometimes, in the case of tightly-wound spirals, there appears to be no symmetry. In the absence of any overall description of how spiral structure occurs, it seems only possible to enumerate a number of conditions that may be important under different circumstances.

First we can consider the purely dynamical problem of a number of mutually gravitating bodies undergoing rotation about a centre of symmetry all in one plane. By considering the instability of motion of this kind B. Lindblad suggested that a spiral structure could develop. It was a feature of his original analysis that the spiral arms so formed would 'open up' in the direction of rotation, rather than trail. However, it has been subsequently demonstrated by P. O. Lindblad, by the use of numerical techniques using a computer, that though the 'leading-arm' structure occurs temporarily, it is followed by the development over a much longer period of time of a 'trailing-arm' structure.

The observational determination of whether spiral arms lead or trail was for some time an unresolved question. For an external galaxy to be discussed it is necessary for it to be intermediate between 'face-on' and 'edge-on' and to be able to distinguish (a)

which of the two sides is approaching and which is receding, (b) which is the near-side edge and which is the far-side edge, and (c) whether the spiral arms open up in an apparently clockwise or anti-clockwise sense. The resolution of factor (b) provoked considerable controversy, but it had become generally accepted some fourteen years ago that spirals 'trail', when evidence of spiral structure within our own Galaxy, both by optical and radio methods, seemed to confirm it.

The use of the 21-cm hydrogen spectrum line in radio-astronomy studies of our own galaxy has been described in the 1962 edition of this *Yearbook* by R. H. Garstang and by R. C. Jennison. Since that time the delineation of the spiral structure of our own Galaxy has not become much clearer. The 21-cm observations depend, for their interpretation, on an adopted velocity model of the Galaxy, partly derived from the 21-cm observations themselves and partly dependant upon our knowledge of stellar motions as well as on theoretical mass-distribution models of our Galaxy. Using this kinematic model the Doppler-shifted intensities of the sharp spectrum line in specific directions around the galactic plane are converted to hydrogen densities at specific locations. In this way some kind of spiral pattern for the distribution of interstellar hydrogen (un-ionized) is built up. It has been difficult to reconcile the two main contributions to this pattern from Leiden and Sydney radio telescopes, for the northern and southern hemispheres respectively, without making *ad hoc* changes to the velocity model, such as postulating an overall expansion, and even then there are unresolved difficulties. Much recent interest in 21-cm work has turned to the examination of previously unforeseen features, such as the recently-discovered interstellar clouds travelling towards the galactic plane from intergalactic regions, and to the intergalactic regions, and to the analysis of fine structure in interstellar hydrogen clouds.

The differential motion in the galactic plane at the Sun's distance from the galactic centre is specified by the two Oort constants A and B, both having the physical dimensions of an angular rotation. The first represents the local shearing. It is

determinable from radial velocities alone, taking stars in a region one to two kiloparsecs in radius around the Sun, and takes the value A = 15 Km./sec.Kpc. The second refers to the total motion of the local aggregate in a stationary frame and is only with difficulty determined from proper motion data. There results the relationship $A - B = \omega_c$, the circular velocity of motion around the centre of the Galaxy expressed as an angular velocity. In round figures we have $B = -10$ Km./sec.Kpc. The value of ω_c is then 25 Km./sec.Kpc., which corresponds to a galactocentric period of 250 million years and a linear velocity, with the Sun's distance to the galactic centre equal to 10 Kpc., of 250 Km./sec. Under the shearing motion represented by A, a cloud starting off with a spherical shape would be drawn out into a strongly trailing spiral shape in considerably less than 10^9 years. This is greater than the age of the bright blue stars, but much less than the age of the disk itself, as indicated by the older disk stars such as the Sun. Thus it is imperative to envisage a process whereby either the spiral arms constantly re-form out of the interstellar material, or else they are constantly being replenished in their existing form by a systematic building up on their inner edges. In cases like that of our own Galaxy, where the arms, at any rate as far as the gas is concerned, are ill-defined, a constant re-forming process is indicated. It is possible that such a process could come about as a result of an instability dependent upon the gas dynamics of the situation, rather than the particle dynamics of Lindblad. It is difficult to see how any degree of symmetry right across the system might arise in this way, and it is necessary to seek some other explanation for the strongly-defined open arms of the 'late-type' spirals, that follow the shape of approximately logarithmic spirals. It is not yet clear what importance magnetic fields may have. It is possible that there is a systematic flow outwards along spiral arms, connected with a magnetic field. The presence, in our own Galaxy, between us and the galactic centre of an expanding '3 Kpc.' arm, moving outwards at something like 80 Km./sec. will possibly lead to evidence of outward motion connected with all spiral arms, but this possibility seems somewhat unlikely.

For the barred systems we can imagine that these are the cases where the condensation into a needle-shaped body, rather than a disk, has taken place. Self-gravity dominates within the main body, and rigid rotation takes place. At the ends of the bar it has been suggested that a form of evaporation could take place, resulting in a gradual shrinking of the bar and the leaving behind, in the outer regions, of strongly trailing arms, or in certain cases rings. It is possible that magnetic effects are important here, too. Traces of spiral arms have been found in the Magellanic Clouds outside the main bars, suggesting that these small galaxies are not truly described as irregulars, but it seems unlikely that our own Galaxy is a barred system, and none of the giant near-by systems are barred spirals, so we do not have the opportunity of examining a typical barred system in detail.

Finally, it ought to be noted once again that the distribution displayed by the blue giants is not necessarily that of the total mass and does not always correspond to a spiral pattern traced by other kinds of objects. In our own Galaxy the clusters and bright blue stars do not, apparently, agree closely with the distribution of the hydrogen clouds in their near-circular outlines. In M 51, the first of the spirals to be described by the Earl of Rosse, Zwicky has shown that if the blue stars in their spiral pattern are entirely removed by means of a photographic positive-negative superposition technique, a substantial modification to the spiral pattern emerges, suggesting that the yellow and red giants follow a different, but related, spiral pattern of their own.

In summary, we have a situation where we know that the spiral arms are characteristics of systems in which stellar formation from interstellar material is taking place. We do not know the exact circumstances of spiral structure, but suggest that various causes lead to such a pattern in differentially-rotating self-gravitating systems of the size of galaxies. Such vague notions are the modern counterpart, and perhaps not a great advance upon, the 'whirlpool' or 'vortex' picture referred to by the late nineteenth-century astronomers, who were the first to wonder what the spiral forms represented.

Planetology or Geology Applied to the Planets

GENNADIY N. KATTERFELD (President, Commission of Planetology, G.S. ass. Academy of Sciences of the U.S.S.R. and Dept. of Geomorphology, Leningrad State University)

Planetology ('astrogeology' or 'planet geology') is an intermediate science – lying somewhere between astronomy and geology – that studies the comparative morphology and geology of the planets and their satellites.* Subjects studied by the planetologist include the morphology, substance, structure and historical development of the lithospheres of the planets and their satellites, while the basic methods of investigation employed are respectively morphogenetic, geological and in particular photogeological – with some adjustment made to allow for variations between physical conditions on earth and on the other planets. In studying the nature and structure of the substances that make up the surface of the Moon and the other planets, wide use is made of astrophysical methods of investigation into such subjects as polarization, albedo, colorimetry and luminescence. In addition, use is made of radio astronomy and – for research into the volcanic structures of the Moon and Venus – spectroscopy. Statistical methods of research are also important for elucidating the origin and formation of planetary relief (i.e. the origin of lunar craters and cirques, the formation of lunar maria and the surface of Mars, and the origin of the oases on Mars).

* Cf. 'Planetology, a study and explanation of the surfaces of the planets'. Webster's Approved Dictionary, p. 750 (The World Publishing Co., Cleveland and New York, 1944).

Since 1955, March 15, there has been a Commission of Planetology (formerly 'astrogeology') attached to the All-Union Geographical Society of the Academy of Sciences of the U.S.S.R., in which the participating scholars include geologists, volcanologists, geomorphologists, astronomers, geophysicists and geochemists from Leningrad, Moscow, Petropavlovsk (Kamchatka), Alma-Ata, Novosibirsk, and other cities of the Soviet Union. It comprises three sections: one for astronomical geology, one for selenology, and one for areology and areography. In 1965 May the Commission held its fifth All-Union Conference on the problems of planetology with over 150 people taking part and representing 75 scientific research establishments and organizations. Other participants in the work of the Conference included leading selenologists from Hungary, the U.S.A., Czechoslovakia, Bulgaria and the German Democratic Republic. There is also a branch of astrogeology in the Geological Service of the U.S.A., whose basic task is research into – and the photoselenological mapping of – lunar craters. At the beginning of 1966 a Department of Planetology was established in Czechoslovakia, headed by Professor Konrad Beneš of the Ostrava Mining Institute. Scientists from England, Japan, Hungary, Bulgaria, the German Democratic Republic and certain other countries are also working in the field of planetology. In the Soviet Union the Leningrad State University has for the past seven years been offering a course on the problems of comparative planetology.

From all this we may conclude that although it is *young*, rather than old, planetology as a science is no longer entirely new.

The basic divisions of planetology at present, apart from geology, are as follows: selenology, areology, hermesology (the 'geology' of Mercury) and aphrology (i.e. the 'geology' of Venus. The term 'aphrology' was proposed by Soviet scientists in 1964 as a replacement for the excessively long alternative, 'aphroditology').*

Selenology (sometimes referred to as 'selenogeology') is at the moment the most important and (after geology) most highly

* From the Greek names for the Moon, Mars, Mercury and Venus, viz. Selene, Ares, Hermes and Aphrodite.

developed field of planetology. It is also the oldest branch of it, 1965 having been the 300th anniversary of the publication of the first ever selenological work, which was written by Robert Hooke in 1665. Hooke (1635–1703), together with Athanasius Kircher (1601–80) and Nicolaus Steno (1638–86), was one of the founders of geology. Selenology can in turn be split up into a number of subdivisions that correspond with its basic lines of inquiry, which include studies of the lunar lithosphere's relief, composition, structure and historical development. These subdivisions are selenomorphology, selenopetrography together with engineering selenology, selenotectonics, and historical selenology.* Modern selenology's principal aims are the elucidation of: (1) The nature of lunar soils and rock and an evaluation of their resilience; (2) The origin of the ring structures in the Moon's relief; and (3) The history of the development of the Moon's surface and lithosphere. Engineering selenology, which is concerned with the study of lunar soils and their terrestrial analogues, is at the moment, thanks to its well known great practical value, the most rapidly developing branch of selenology. (Suffice to point out that in the U.S.A., for example, twenty-eight scientific research organizations are at present occupied with the problems of engineering selenology.)

The majority of selenologists are of the opinion that both the relief and substance of the Moon's surface are of a tectonomagmatic nature and are only to a lesser degree (to a considerably lesser degree according to Jack Green, 1964 and 1965) dependent upon the fall of cosmic particles on to the Moon's surface. The substances that can most fruitfully be compared with the extremely porous lunar rock are such terrestrial volcanic products as scoriæ, tuff and pumice. The systems of lunar rays, it is thought, are formed not only by volcanic dust and the fall-out from exploding meteors, but also include fragments of various sizes that have been ejected during the process of formation of craters. These rounded lunar pebbles, which can be seen in the foreground of

* Cf. 'Selenology, the science of the formation of the Moon's crust, lunar "geology"'. The Shorter Oxford English Dictionary, vol. 2, p. 1834 (O.U.P. 1933).

the circular panoramas photographed by Luna–9 and Luna–13, are most likely volcanic bombs ejected from the nearest volcanic craters. The insignificant depth to which they are embedded in the Moon's surface bears witness both to the fairly high degree of resilience of that surface (not less than 1 kg-cm^2 according to indirect data) and to the low specific gravity and low force of impact of these 'stone-like formations'. It is highly improbable that they could be meteorites or even stones that have rolled down from the slopes of the nearest mountains, for we find no mountains in the vicinity of Luna–13's touchdown point.

As distinct from the earth, the tectonic structure of the Moon's upper layers is not folded but block, which is connected with the absence on the Moon of any sedimentary deposits and the high incidence of explosive dislocations. On the Moon (as also on Earth and on Mars) the diagonal system of N.W. and N.E. faults is the one most commonly found, of which N.W. is the predominant direction; then come meridional systems and in last place, by numerical frequency, the E.–W. system. As a result of observations and computations made on the basis of photographs, the amount of horizontal shift on faults on the Moon's surface has also been fixed, giving a displacement that varies from a few up to as much as 32 kilometres. The best known example of this kind is the dislocation along the fault that cuts across the crater Capella, with a displacement of 12 kilometres. Apparently the horizontal shifts on the moon were first described in 1929 by the Belgian selenologist, A. Piérot, in an article entitled 'Le Plateau de Censorinus'. One fact of the greatest interest that pertains to *all* the Moon's horizontal dislocations is that those with a N.W. orientation travel to the *right*, while those with a N.E. orientation travel to the *left*. This points to their having been formed as a result of planetary forces, i.e. as a result of polar deformation of the lunar globe determined by the Moon's rotation.

In 1896 the French selenologists, M. Loewy and P. Puiseux, determined five basic stages in the history of the Moon's development. They were (1) Pre-selenological, i.e. that stage of the lunar surface's development that preceded the formation of a hard

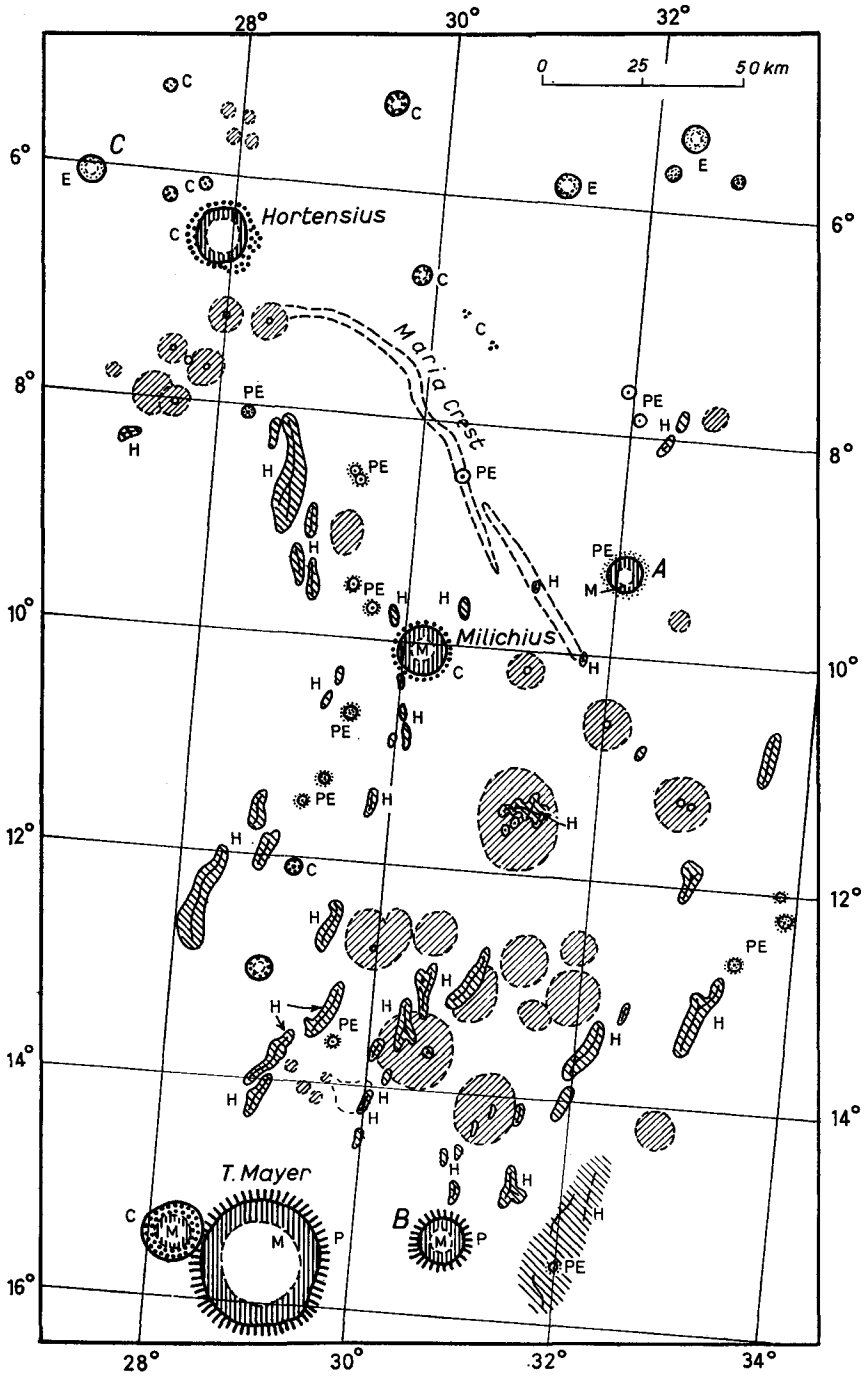
lunar crust; (2) The stage of the formation of the initial lunar crust and the appearance of the first fissures; (3) The ante-mare stage; (4) The mare stage; and (5) The post-mare stage.

Subsequently W. Hommel (1919), H. McEwen (1929), A. V. Khabakov (1949, 1960), E. Shoemaker and R. Hackman (1960, 1962, 1963) subdivided the ante- and post-mare stages of lunar history into smaller periods of growth. If we collate all the facts at our disposal at the present time, the lunar time scale can be represented in the form of the following seleno-chronological table, where the order of the periods of formation of relief and structure is signified by consecutive numbers, beginning with the very earliest and ending with the latest:

Era	*Index*	*Period*		*Index*
Post-mare	PM	VIII	Contemporary epoch	M
		VII	Copernican	C
		VI	Eratosthenic	E
Mare	M	V	Oceanic (Procellarian)	O
Ante-mare	AM	IV	Ptolemaic	P
		III	Altaic*	A
		II	Hipparchic (Apennine)	H
		I	Antiquity	Ant.
Pre-selenological				

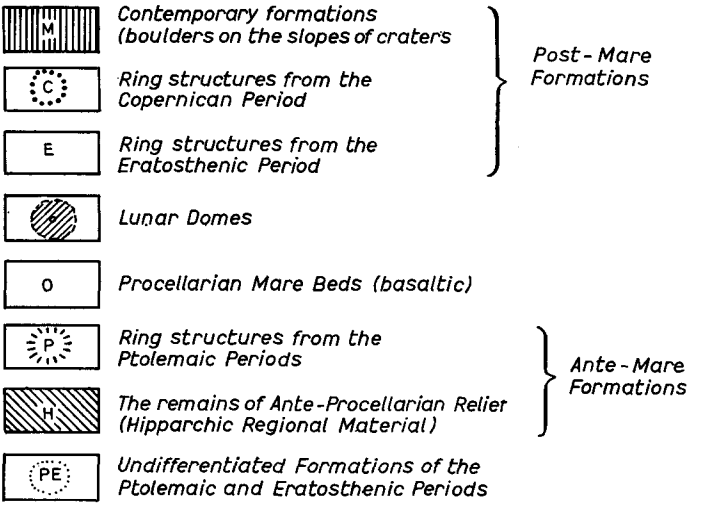
*The earliest stage in the development of lunar maria, whose existence was demonstrated by P. Fauth (1907), Hommel (1919) and McEwen (1929).

In particular, the formation of the most recent lunar craters must be assigned to the Contemporary epoch (these include craters with a dark halo), together with open faults of the type of


28°
30°
32°
0
25
50 km
6°
8°
10°
12°
14°
16°
Hortensius
Maria crest
Milichius
T. Mayer
A
B
C
E
H
PE
M
P

the Hyginus and Ariadæus rifts, with terraces on the slopes of older craters and cirques, and also, perhaps, with certain of the lunar domes. The latter are situated entirely within the bounds of lunar maria and gravitate for the most part towards maria of the epicontinental variety, their physical features either having been formed by a magmatic swelling of the mare surface (as postulated in the hypothesis of Kurd von Bülow, 1964) or else resembling terrestrial shield volcanoes with fluid basaltic lava (as postulated in the hypothesis of William Pickering, 1906 and 1920).

The exact dating of key events in the Moon's history and the duration of given periods remain to a considerable extent obscure. According to A. V. Khabakov (1960), who based his calculations on a volcanic selenological hypothesis, the duration of the Contemporary epoch amounts to 25,000 years, and of the Copernican and Eratosthenic periods, taken together, to 2.5–5 million years, while the duration of the entire known segment of the Moon's



Map I. Selenological Map of the Dome Field Milichius on the Moon
North is at the bottom.

history, read off against the natural selenomorphological calendar, does not exceed 200 million years. According to the calculations of Shoemaker, Hackman and Eggleton (1963), on the other hand, which were also based on a statistical evaluation of the frequencies of lunar craters (though one must take into account the fact that all the craters were assumed to be of meteoric origin), the lunar maria were formed 4–5 thousand million years ago; hence the Copernican and Eratosthenic periods taken together comprise the major part of selenological time. In this scheme of things the Copernican period occupies just under half of this entire interval (cf. Shoemaker and Hackman, 1963), i.e. about two thousand million years (cf. Shoemaker, 1964). There is no doubt, however, that there exist on the moon both volcanic (caldera and maar) and meteoric craters.* Therefore one should in fact regard both these sets of calculations of the absolute age of lunar maria – Khabakov's (of the order of 10^7 years) and Shoemaker's ($4{\cdot}5 \times 10^9$ years) – as nothing but probable theoretical indications of the *lower* and *upper* limits, between which the true age is to be found. But what, in fact, is this age? It is the writer's opinion that one should take an intermediate indication of 10^8 years for the age of the Procellarian mare surfaces; it corresponds most objectively to the morphogenetic conditions of the Moon's surface and is in any case a fairly reliable order of time.†

A more exact indication of the age of the maria and the duration of selenological periods is hindered by our lack of knowledge of the true numerical proportions of volcanic and meteoric craters on the Moon. Nevertheless, no matter what degree of exactitude might ultimately be attained, the order of the evaluation just made would probably remain unchanged. As has been shown by the

* Cf. articles by K. von Bülow, J. Green, G. N. Katterfeld and G. S. Steinberg in the collection, 'The Fifth Planetological Congress, 10–15 May, 1965' (Vse-soyuznoye geograficheskoye obshchestvo/ All-union Geographical Society, Leningrad).

† It should be noted that this indication of the order of time involved corresponds with the more practical estimates that were made with the aid of a meteoric calculator of lunar time by K. A. Lyubarsky (1959), T. Kreiter (1960) and G. Fielder (1963).

research that was recently carried out with the aid of the Soviet automatic station Luna–10, the mare lava on the moon is of a basaltic composition. Within the area of the Mare Imbrium it forms an almost continuous bed with an average thickness of just over a kilometre. These aforementioned data pertaining to the age, composition and thickness of the Procellarian system indicate the possibility of a comparison with the gigantic laval fields known to us on Earth, which came into being in the Mesozoic age somewhere between 70 and 230 million years ago. Thus, for example, the chalky basalt of the Deccan Plateau in India has an average thickness of approximately 0·6 km. and covers an area of almost 500,000 sq km. The floor of the Earth's ocean basins, which was basically formed during the same era, is also composed of basalt, particularly (as was shown by the first deep-water bore of the earth's crust) Triassic basalt. The absolute age of Mesozoic rock amounts to $0{\cdot}7–2{\cdot}3\times10^8$ years, i.e. the age of these basaltic lava beds on earth is of the same order as the age of the Procellarian period. This means that the Mare era in selenological history corresponds approximately to the Mesozoic age in geology, therefore the Eratosthenic, Copernican and Contemporary periods of the Post-mare era in lunar history can be provisionally equated with the Palæogene, Neogene and Quaternary periods of the Cenozoic era of terrestrial history.

The conclusions of selenology, which are arrived at via a comparative geologico-morphological study of the Earth and Moon, not only aid us in elucidating purely selenological phenomena but are also of major importance in the solution of geological problems.

No problem in *Areology* has attracted so much attention to itself or provoked such sharp and lengthy disputes as the question of the origin of the celebrated 'canals' on Mars. Now, however, even this almost century-old planetological riddle is on the verge of solution, thanks to the application of new methods of planetological research. The tectonic nature of the Martian 'canals', which was earlier postulated by a whole series of scientists

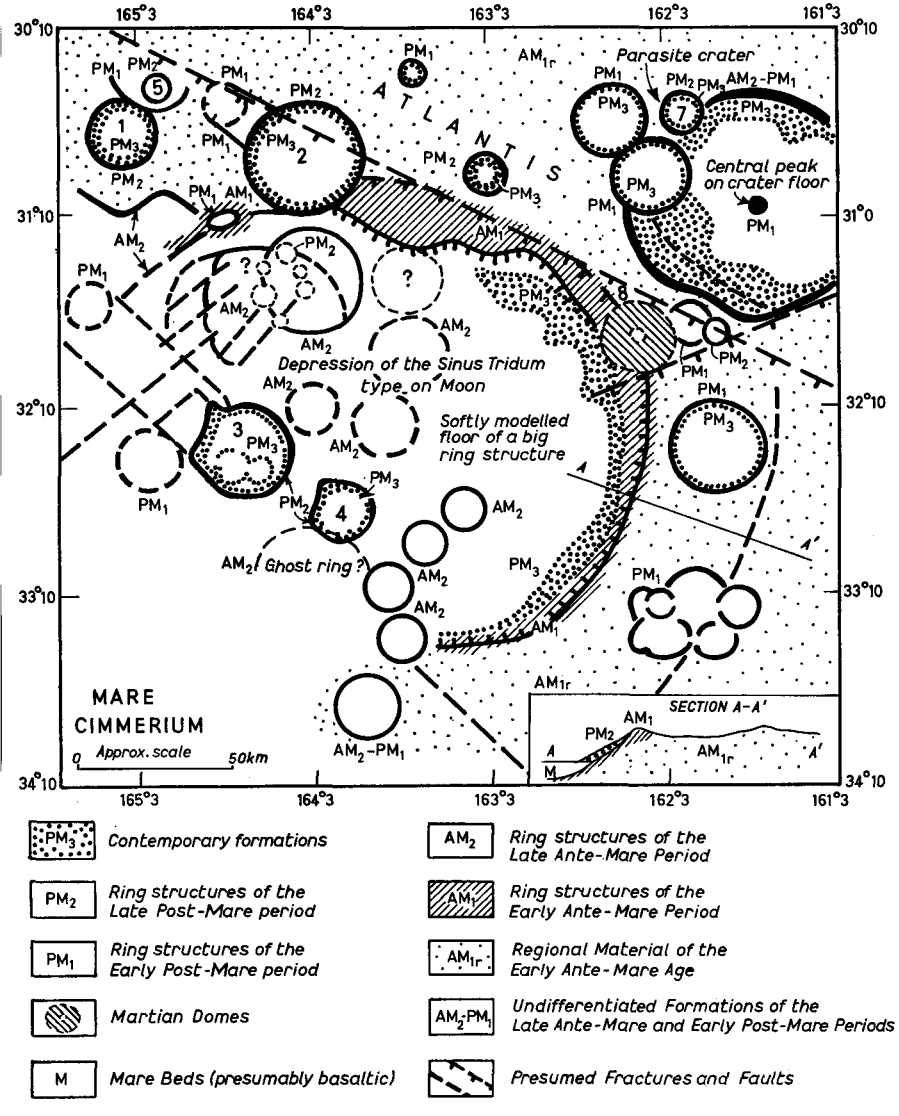
(G. Schiaparelli, 1899, p. 34; W. Pickering, 1906, p. 179; G. Delmotte, 1923; O. Jessen, 1948, p. 151; A. V. Khabakov, 1949; G. N. Katterfeld, 1955 and 1959; Kurd von Bülow, 1960; Shotaro Miyamoto, 1961; G. Fielder, 1963) was recently demonstrated empirically by the American probe Mariner 4. Clearly visible on its first three photographs of the surface of Mars, taken to the east of Trivium Charontis, are dark stripes and linear tectonic dislocations that are localized along the 'canals' Erebus and Orcus.*

Mars, like the Moon, is covered with a multitude of craters and cirques of varying dimensions. On photographs 3–15 taken by Mariner 4 (1965 July) more than 100 craters and cirques can be counted with a diameter of from 4–150 km. Nine of them, moreover, have peaks. Inasmuch as Mariner 4 photographed approximately one per cent of Mars' entire surface, the overall number of ring structures of these dimensions must come to somewhere around 10,000. By analogy with the Moon one would expect Mars also to have both meteoric and volcanic craters. In this connexion the task of finding criteria for differentiating between exogenous and endogenous ring structures becomes even more urgent. The criteria for isolating endogenous ring structures include the presence of the following features: (1) Terracing of the inner slopes; (2) Concentric embankments; (3) Crater depressions and orifices on the tops of central and marginal peaks; (4) Groups of ring structures; and (5) Lines of ring structures.

It is possible that certain of the 'canals' on Mars are in fact chains of craters strung out along the courses of tectonic fractures.

Mariner 4's photographs show ring structures in varying degrees of preservation and with varying degrees of prominence. Taking all in all, these must be structures of differing ages, moreover the laws of their consecutive formation, extrapolated by analogy with the Moon, lose none of their validity in the case of Mars.

* Over-hasty assertions by some writers to the effect that 'there are no canals on Mariner 4's photographs can be explained for the most part by the erroneous choice of a chart of Mars, namely that of E. C. Slipher. This chart differs significantly in many respects from other areographical charts such as those done by Antoniadi and Ebisava, and Camichel and de Mottoni.



Map II. Areological Map of the Atlantis Region on Mars
(Drawn from photograph no. 11 taken by Mariner 4, 1965, 7.15)

It is possible that the formation of the planet's surface relief also assumed the character of development by stages, with eras of evolutional development similar to the Ante-mare, Mare and Post-mare eras of the Moon.

The framework of this article does not allow me to dwell in detail on the other branches of planetology listed earlier. Let me just note that Mercury, Mars and Venus occupy an intermediate position between the Moon and the Earth on the evolutional ladder of structural development; and the level of their structural organization is defined by their planetal mass Mercury stands between the Moon and Mars on this ladder, while Venus is closer to our own planet (cf. G. N. Katterfeld, 1962 and 1965). None of the planets of the terrestrial group, except for the Earth and Venus, has a central core, and none of them, except for the Earth, has a magnetic field or poles of radiation (cf. G. N. Katterfeld, 1962; G. I. Pokrovsky, 1962; P. Hédervári, 1963).

The fields of enquiry that come closest to planetology and that are now developing on the basis of the latest achievements of planetary physics are *planetography* and *astrobiology*.

Planetography (also known as 'astrogeography') is the study of nature on those bodies in the Solar System that resemble the earth. It studies the development of the geographical envelopes of planets and encompasses, together with parts of other disciplines, geography, selenography and areography. Our better knowledge of the earth's geographical envelope enables us to apply the theories of physical geography to a study of the nature of other planets (cf. I. M. Zabelin, 1959 and 1962). And the conclusions of planetography, in turn, derived from a comparative study of nature on the earth and on other planets, enables us to improve our knowledge of the development of our own geographical envelope. Because of the absence on the Moon, except for a lithosphere, of all the basic components of a geographical envelope, namely an atmosphere, a hydrosphere, and a biosphere, in order to describe it one needs simply to list its morphological character-

istics. On Mars and Venus, where in addition to a lithosphere there is an atmosphere (extremely rarefied for Mars, in comparison with those of the Earth, but somewhat denser for Venus), *Climatology* also becomes relevant. But such a particular branch of geography as *Oceanography* will forever remain inapplicable on the other planets of the Solar System (with the problematical exception of Venus).

Astrobiology is concerned with a comparative study of terrestrial and extra-terrestrial forms of organic life. Practically speaking it is possible at the moment only to study the vegetation of Mars. The emergence of astrobiology as a science is linked with the name of the outstanding Soviet scientist, G. A. Tikhov, who in 1947 started the first scientific research centre in the world for astrobotany. In recent years much effort has gone into simulating physical conditions on Mars and the other planets and attempting to establish what the possibilities might be for various forms of terrestrial organic life to exist under such conditions. One thing that is becoming more and more clear is the role of the Earth's *nucleus*, its rotation about an axis and the resulting generation of magnetic fields as important factors in the development on our planet of highly organized forms of life. Given the present state of scientific knowledge in this sphere, the much debated question of whether rational beings exist or not on Mars and on the other planets of the solar system can only be answered in the negative. It is safe to say that in all probability *there are no rational beings of the type of homo sapiens on any of the other planets.* Mankind, it appears, is truly alone in the Solar System.

Translated by Michael Scammell.

BIBLIOGRAPHY

Planetology

Katterfeld, G.N.—'On the Nature of the Linear Structures on Mars' (in *Transactions of the Astrobotanical Section of the Academy of Sciences of Kazakhstan*, Vol. 4, Alma Ata, 1955).

— 'On the Question of the Tectonic Origin of the Linear Formations on Mars' (*Proceedings of the Geographical Society of the U.S.S.R.*, vol. 91, no. 3, Leningrad, 1959).

— 'The Nature and Origin of the Earth' (Moscow, 1962).

— 'The Problems and Methods of Selenology' (*Proceedings of the Geographical Society of the U.S.S.R.*, vol. 97, no. 2, Leningrad, 1965).

Hain, V. E. and Khodak, Yu. A.—'Problems in Comparative Planetology and the Stages of Development of Planets of the Terrestrial Group' (*Fifth Planetological Congress*, 10–15 May, 1965. Pub. by the All-union Geographical Society, Leningrad, 1965).

— 'Volcanic Activity on Mars' (in *Nature*, no. 8, Moscow, 1965).

Khodak, Yu. A.—'Problems of Selenology and the Significance of Geological-Morphological Methods in Studying the Moon (*Journal of the International Lunar Society*, vol. 3, no. 1, pp. 20-24, 1966).

— 'Types, Age and Origin of the Lunar Ring Structures' (*Journal of the International Lunar Society*, vol. 3, no. 2, pp. 36–43, 1966).

— 'Selenology' (in *The Shorter Geographical Encyclopedia*, vol. 5, pp. 180–1, plus two maps. Pub. by Sovetskaya entsiklopedia, Moscow, 1966).

— 'Bibliography of Planetology, 1665–1964' (Pub. by All-union Geographical Society, Leningrad, 1966).

Lyubarsky, K. A.—'A Tentative Definition of the Absolute Age of Lunar Formations' (*Bulletin of the All-union Astronomical-Geodesic Society*, no. 25 (32), Moscow, 1959).

Menier, S.—'Comparative Geology, or the Geology of the Heavenly Bodies' (1874, trans into Russian from French, St. Petersburg, 1896).

Pokrovsky, G. I.—'Radiation Belts of the Heavenly Bodies' (in *Nature* no. 8, Moscow, 1962).

Khabakov, A. V.—'On Some Basic Questions of the Historical Development of the Lunar Surface' (Moscow, 1949).

— 'Characteristic Peculiarities of the Moon's Relief. The Basic Problems of the Genesis and Consecutive Development of Lunar Formations' (*in 'The Moon', a collection of articles edited* by A. V. Markov, Moscow, 1960).

Shoemaker, E. and Hackman, R.—'Stratigraphic Basis for a Lunar Time Scale' (Russian trans in the Collection *New Light on the Moon*, pub. by the Academy of Sciences of the *U.S.S.R.* Moscow and Leningrad, 1963).

(Translator's note: The bibliography that follows is in the Latin script.)

Planetography and Astrobiology

Zabelin, I. M.—'Theory of Physical Geography', pp. 84–115, Moscow, 1959.

— 'Geography and the Planets' (Pub. by Znaniye, Moscow, 1962).

Katterfeld, G. N.—'A Discussion of the Problems of Astrobiology' (*Proceedings of the Geographical Society of the U.S.S.R.*, vol. 97, no. 2, Leningrad, 1963).

Lyubarsky, K. A.—'Notes on Astrobiology' (Moscow, 1962).

Moore, P.—'The Planet Venus' (London and New York, 1959).

Schiaparelli, G.—'The Planet Mars' (St. Petersburg, 1899).

Tikhov, G. A.—'Astrobotany' (Alma-Ata, 1949).

Sharonov, V. V.—'The Nature of the Planets' (Moscow, 1958).

Recent Advances in Astronomy

PATRICK MOORE

The time has long past when astronomy can be sharply distinguished from space research. The two fields of research are closely linked; thus at the time when these words are being written (1967 August) two probes, one Russian and one American, are on their way to the planet Venus, and may well provide information telling us for certain whether or not the surface temperature of that curious planet really is of the order of 800 degrees Fahrenheit.

Up to 1967, space research had been carried through with no 'first-line' casualties. (The peculiar stories about unannounced Russian deaths in space may be totally disregarded.) It therefore came as a most unpleasant shock when two tragedies occurred. In the first, three United States astronauts – Grissom, White and Chaffee – were killed during a disastrous fire in their capsule during a rehearsal prior to a launch. In the second, the Russian astronaut Komarov crash-landed in his capsule, and had no chance. Undoubtedly both the major space-programmes have been badly disrupted, but the personal tragedies outweigh all other considerations. One can only hope that nothing of the sort will occur again.

Unmanned probes to the Moon have continued to supply vital information, and special mention should be made of the photographs sent back by the U.S. Orbiter vehicles, which are of superb quality. But we must remember that the Solar System is a very tiny part of the universe as a whole: and in astrophysics the advances in knowledge have been just as marked, though less well-known except to the scientific community.

Much depends upon the availability of large telescopes. At the moment, there are simply not enough giant instruments to

cope with all the work needed, and plans for new equipment were announced during 1966 and 1967; in particular, a very large reflector is to be set up in Australia. Meanwhile, the 98-inch Isaac Newton telescope, described by G. M. Sisson in the 1967 *Yearbook*, has been installed at Herstmonceux, and is now in use.

Cosmologically, intense interest is centred upon the quasars, also described (by Dr E. M. Lindsay) in the 1967 *Yearbook*. If the quasars are really remote and super-luminous, we have to confess our total ignorance about their energy-sources; if not, then the red shifts in their spectra cannot be pure Doppler effects, and doubts may be cast even upon the expansion of the universe. Most astronomers believe that the red shifts are indeed Dopplers, and that the expansion of the universe is real; but the last word has by no means been said, and it is hoped that new information will be obtained in the immediate future. Whether we shall ever solve the problem of 'the creation' is open to doubt, but at least we should know more about the past history of the universe by, say, 1978 than we do at the start of 1968.

PART THREE

For Stellar Observers

Most amateurs concentrate upon Solar System studies, largely because it is only since the beginning of the Space Age that professional astronomers have started to concentrate to some extent upon the surface observation of the Moon and planets. However, it is quite wrong to suppose that amateurs are unable to contribute also to stellar research. One of the most fruitful fields is that of variable star work, where there is a great deal of scope. The article by J. S. Glasby, Director of the Variable Star Section of the British Astronomical Association, will show what can be done, and it is hoped that some readers of this *Yearbook* will feel inspired to take up this important and interesting research.

Since Greek letters are used in the charts, it seems worth repeating the Greek alphabet, though it has of course been given here and in earlier *Yearbooks*. The letters are:

α Alpha	ϵ Epsilon	ι Iota	ν Nu	ρ Rho	ϕ Phi
β Beta	ζ Zeta	κ Kappa	ξ Xi	σ Sigma	χ Chi
γ Gamma	η Eta	λ Lambda	o Omicron	τ Tau	ψ Psi
δ Delta	θ Theta	μ Mu	π Pi	υ Upsilon	ω Omega

Variable Stars

J. S. GLASBY

The fact that all stars are not constant in their brightness was discovered in 1596 when Fabricius observed the strange behaviour of the star o Ceti, but it was not until 1638 that its light variations were found to be periodic. Since that time many thousands of variable stars have been discovered, some being many magnitudes brighter at maximum than at minimum, while others vary only slightly in their brilliance. Continued study has shown that such stars may be classified into certain well-defined groups according to the mechanism of their variation.

Eclipsing binaries, typified by Algol and β Lyræ (Fig. 1) are stars which are not intrinsically variable in light, being double stars whose orbital plane of revolution lies virtually parallel to our line of sight such that eclipses occur, either total or partial depending on the inclination of their orbit and the relative dimensions of the components. In the case of the former, the stars are well separated, although visible only as a single star to the eye, and are generally of unequal size and brightness, giving rise to primary and secondary minima separated by maxima of almost constant magnitude.

The light curves of the β Lyræ stars show continuous variation with smoothly rounded maxima, thought to be due to systems consisting of two large stars almost in contact, their shapes grossly distorted from the spherical under the influence of gravity, in some cases surrounded by shells of gas, and always turning the same face towards each other so that their surface areas as presented towards us are constantly changing. Analysis of their light curves, combined with spectroscopic evidence, allows most of the characteristics of these eclipsing systems to be derived.

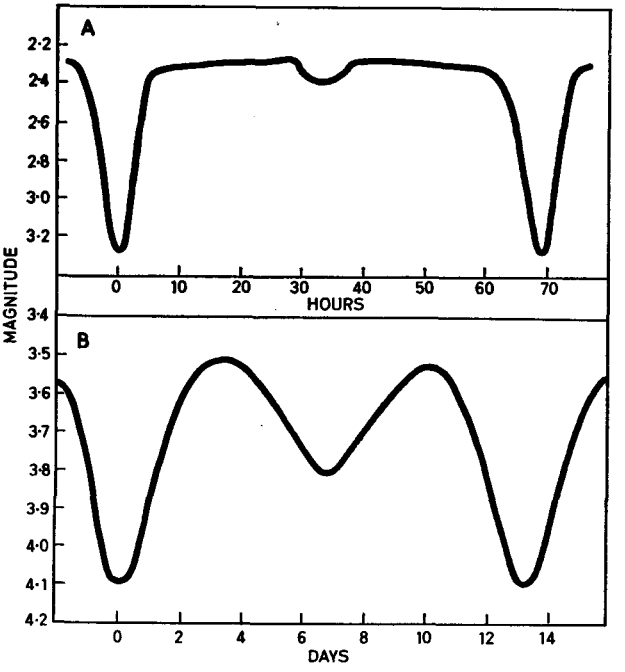


Fig. 1. Light curves of two eclipsing variables
A. Algol
B. β Lyræ

The Cepheids, on the other hand, are stars whose light changes are an intrinsic property of the variable, being associated with physical variations in the star itself. The light curve of a typical Cepheid (Fig. 2), is characterized by a rapid increase in brightness followed by a more gradual decrease, there often being secondary maxima, showing themselves as reasonably well-defined humps on either the ascending or descending branches of the curve. The amplitudes and periods of Cepheids remain constant from one maximum to the next, although at least one Cepheid is known which appears to be changing both its period and character.

The Cepheids are usually divided into two classes; those with

a period of less than 1·5 days and known as the Cluster or RR Lyræ variables, and the classical Cepheids having periods greater than 1·5 days. These stars are of great importance to the astronomer since, in 1912, Henrietta Leavitt of the Harvard College Observatory discovered, from a study of the Cepheids in the Lesser

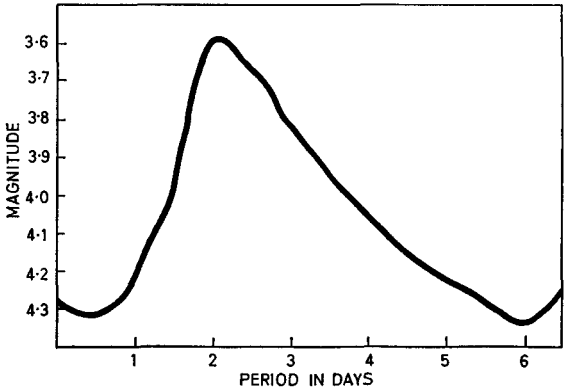


Fig. 2. Light curve of δ Cephei

Magellanic Cloud, a relationship between their periods and their absolute magnitudes. Once the distance to any one Cepheid was known, it enabled astronomers to compute the luminosity and distance of any other. This fact has been of particular value in determining the distances of the nearer extragalactic nebulæ.

Several theories have been proposed to explain the motion, as shown by the Doppler Effect, and the variability of these stars, the most widely accepted being the pulsation theory due to Shapley. Although there is no direct proof of the pulsation theory, it explains very satisfactorily the light variations of these stars.

Another large and important class of stars is the long period variables, the prototype of which, o Ceti, was the first variable to be discovered. These are almost all giant, red stars having low surface temperatures and typical spectra. They have longer periods than the Cepheids, ranging from 100 to 700 days and in general,

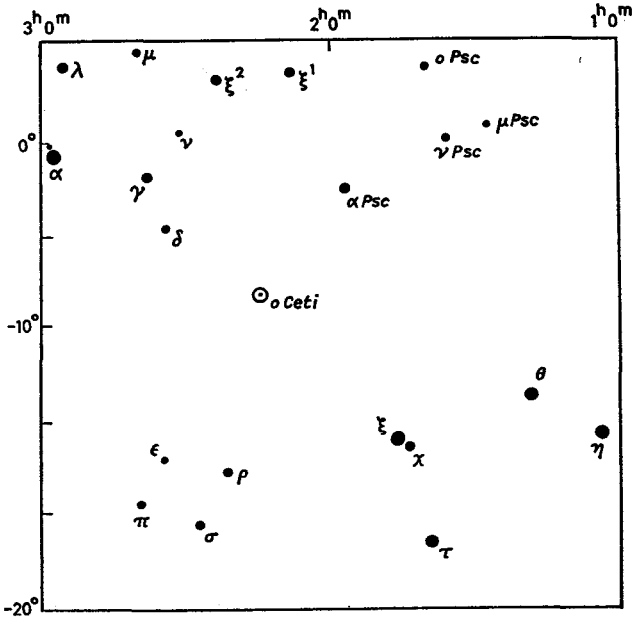


Fig. 3. 9° chart showing the position of o Ceti

TABLE 1

Comparison stars for o Ceti

Star	Magnitude
α Ceti	2·68
γ ,,	3·56
α Psc	3·83
δ Ceti	4·13
ξ^2 ,,	4·27
ξ^1 ,,	4·39
μ ,,	4·62
λ ,,	4·93
ν ,,	5·10
μ Psc	5·26

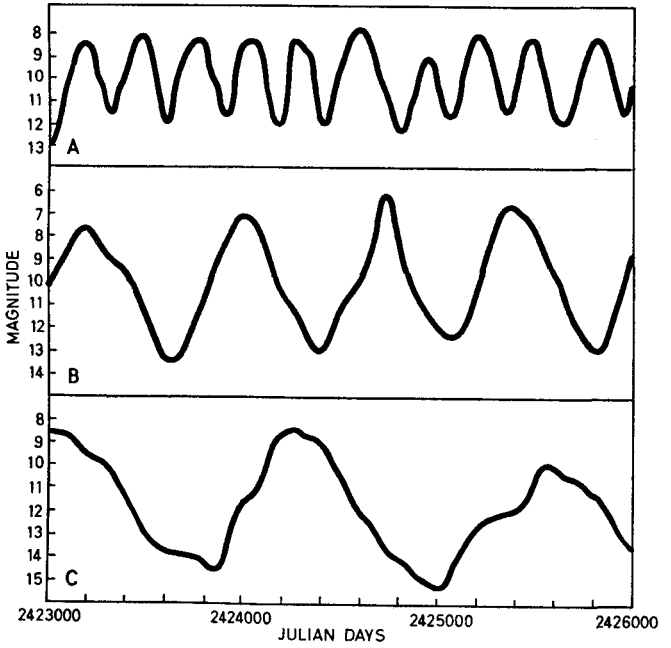


Fig. 4. Light curves of three typical long period variables
A. X Camelopardalis – Period 143 days
B. R Serpentis – Period 357 days, and
C. S Cassiopeiæ – Period 612 days

have far larger amplitudes. Their light variation however, does not possess the precise regularity of the Cepheids; their maxima varying greatly in period, amplitude and the shape of the light curve. Minima are also variable, although to a much lesser degree. Fig. 4 shows the light curves of three long period variables of widely different periods.

Since the characteristics of one maximum cannot be predicted from those which have preceded it, these stars must be kept under continual observation. Spectroscopic investigation of the long period variables has indicated that in addition to variations in size, presumably due to pulsations similar to those of the Cepheids,

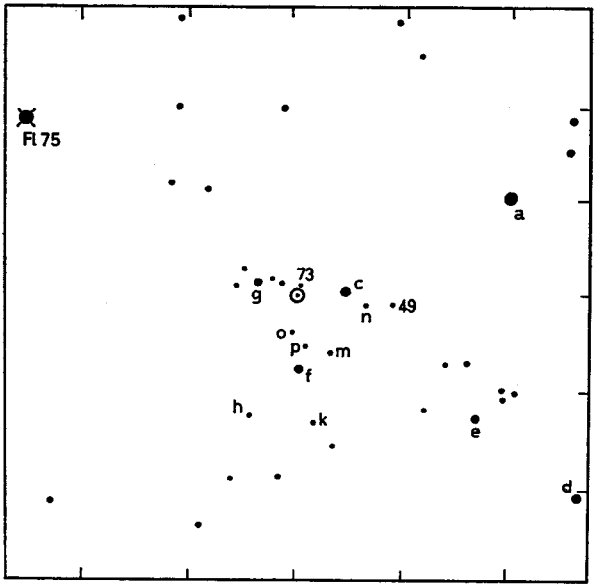


Fig. 5. 1° chart showing the position of SS Cygni

there is intense absorption in the visible region of the spectrum due to titanium and zirconium oxide molecules formed in the atmospheres of these stars because of a periodic lowering of the temperature. That the temperature change is only small is shown by the bolometer, an instrument which measures the total radiation, of all kinds, emitted by these variables. The nature of the spectral changes is such that, although the visible light may change 10,000-fold in luminosity from minimum to maximum, the total radiation may be only doubled.

The irregularities exhibited by the long-period variables are even more pronounced in the semi-regular variables, which are also red stars whose brightness varies more or less regularly but whose amplitudes are generally smaller than those of the preceding group. They may be divided into various classes, although the boundaries between them tend to be extremely vague and ill-

defined. Finally, at the other end of the scale, there are the irregular variables in which it is often extremely difficult to detect any trace of periodicity in their behaviour. The cause of the light variations in these stars is not known, although they frequently exhibit variations in radial velocity, indicating pulsation, and show changes in the intensity of their molecular absorption in their spectra.

TABLE 2

Comparison stars for SS Cygni

Star	Magnitude
a	8·00
c	8·50
d	8·60
e	8·90
f	9·39
g	9·62
h	9·98
k	10·43
m	10·90
n	11·32
49	11·30
o	11·77
p	12·14
73	13·00

Even taking into account all that has been said, the kind of light changes encountered among variable stars is by no means exhausted. A small, but remarkable class of stars is the U Geminorum type, of which only about sixty are known. These stars exhibit sudden, nova-like increases in brightness at irregular intervals, often amounting to four magnitudes in a single night. A typical light curve is that of SS Cygni (Fig. 6). Three kinds of maxima are known for this star – Long, Short and Anomalous, the latter usually exemplified by a more gradual rise to maximum. A small sub-group of this class, the Z Camelopardalis stars, show similar rises but with smaller mean periods and amplitudes and characterized by periods of 'standstill', usually a third of the way

from maximum to minimum, when the star remains at almost constant brightness for periods which may be as short as a few days or as long as eighteen months. Most of these stars have been shown to be binaries consisting of a yellow, dwarf sun similar to our own and a hot, blue-white companion which is the seat of the

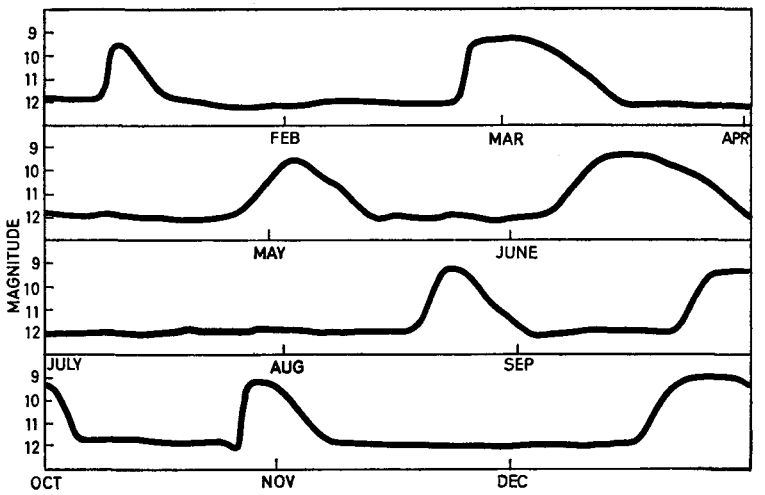


Fig. 6. Light curve of SS Cygni – 1962

nova-like outbursts. Like the long period variables, these stars must be constantly followed, since their rises are entirely unpredictable.

Another very small group of peculiar variables is that typified by R Coronæ Borealis, the brightest and most completely observed of this class. This is the only group of intrinsic variables in which maximum is the normal state. They may remain at maximum for months or even years with only small variations in brightness but will then fade, abruptly and unpredictably, by up to eight magnitudes in a few weeks, the subsequent rise to maximum being slower and marked by wide fluctuations, the star often fading to minimum more than once before attaining its normal maximum.

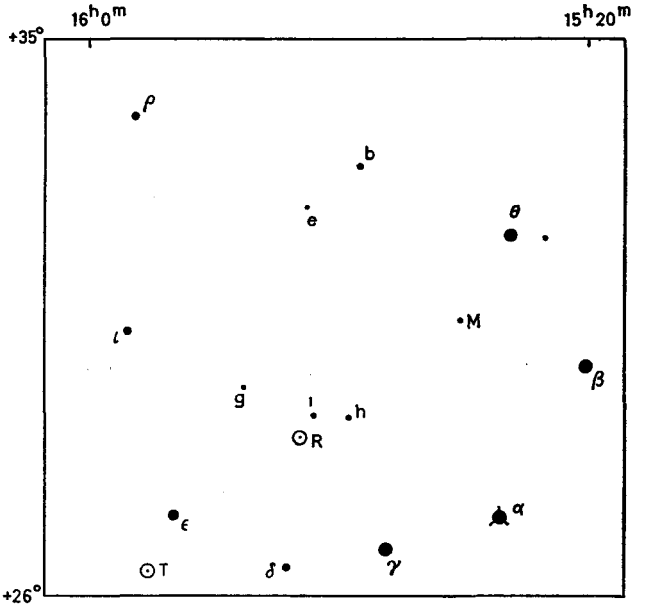


Fig. 7. 9° chart showing the position of R Coronæ Borealis

TABLE 3

Comparison stars for R Coronæ Borealis

Star	Magnitude
b	5·56
M	6·57
e	6·72
l	7·18
g	7·63
h	7·93

The spectra of these stars show that they are unusually deficient in hydrogen, while at the same time there is an abundance of carbon and its compounds in their atmospheres. It is known that the temperatures of these stars are very close to the temperature

at which carbon condenses, and it has been suggested that the light fluctuations are due to the formation of clouds of carbon particles. A detailed study of this group has indicated that pulsation does not appear to be the underlying cause of their variability.

Certainly the most spectacular of all variable stars are the novæ, dim stars which, abruptly and without warning, increase in

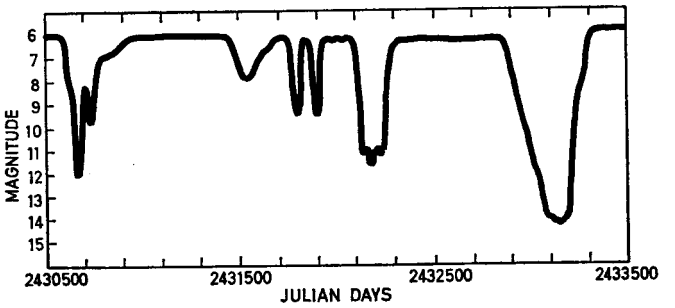


Fig. 8. Light curve of R Coronæ Borealis

brilliance by many magnitudes, sometimes outshining all other stars. Novæ remain at their maximum brightness for only a short time before fading to their original magnitude, usually over a period of a few years. On the basis of the shape of the light curve, novæ may be divided into two groups. The 'rapid' novæ reach their maximum in two or three days, the decline also being rapid in its initial stages before the descent to minimum becomes progressively less steep. The 'slow' novæ, on the other hand, possess a fairly steady rise to maximum often taking two weeks and remain at maximum for several months before fading gradually and with many small fluctuations.

It has been estimated that between twenty and thirty novæ occur each year, but many are so faint, even at maximum, that they escape notice. This comparative frequency of nova outbursts in the Galaxy would suggest that either all stars become novæ at some time during their careers or that if only certain types of star are capable of becoming a nova, then recurrent outbursts must occur from time to time.

Several recurrent novæ have been discovered; T Coronæ Borealis had maxima in 1866 and 1946, RS Ophiuchi in 1901 and 1933, U Scorpii in 1862, 1906 and 1936, while T Pyxidis has erupted on at least four occasions, in 1890, 1902, 1920 and 1945.

Finally, mention must be made of the supernovæ, stars whose light curves show marked similarities to those of the ordinary novæ, but differ from them in their very large amplitudes, often as much as twenty magnitudes, and their unique spectroscopic characteristics. Three supernovæ are known to have occurred in our own Galaxy: Nova Cassiopeiæ, which appeared in October, 1572 and was well observed by Tycho Brahe, Nova Ophiuchi of 1604 and the bright star in Taurus recorded by the Chinese in 1054, the remnants of which now form the Crab Nebula. A star observed in Lupus in 1006 may also have been a supernova.

The mechanism of nova and supernova outbursts is not yet fully understood, although it would appear that in the former case, only an outer shell of stellar material is thrown off, whereas in a supernova explosion, a large percentage of the star's mass is expelled.

As mentioned earlier, many types of variable stars must be observed continuously and much of this work is in the hands of amateurs. Charts are issued (Figs. 3, 5 and 7) by the Variable Star Section of the British Astronomical Association and by the American Association of Variable Star Observers together with sequences of comparison stars for each variable which enable the brightness to be estimated with a high degree of accuracy. Light curves for many variables are published annually from which the dates of maxima and minima may be computed. This growing accumulation of observations is of immense value, and is very necessary if we are to reach any definite conclusions concerning the widely different mechanisms underlying stellar variability.

Some Interesting Double Stars

The pairs listed below are well-known objects, and all the primaries are easily visible with the naked eye, so that right ascensions and declinations are not given. Most can be seen with a 3-inch refractor, and all with a 4-inch under good conditions, while quite a number can be separated with smaller telescopes, and a few (such as Alpha Capricorni) with the naked eye. Yet other pairs, such as Mizar-Alcor in Ursa Major and Theta Tauri in the Hyades, are regarded as too wide to be regarded as bona fide doubles!

Name	*Magnitudes*	*Separation,"*	*Position angle, deg.*	*Remarks*
Gamma Andromedæ	3·0, 5·0	9	060	Yellow, blue. B is again double (0".4) but needs a larger telescope.
Zeta Aquarii	4·4, 4·6	2·6	291	Becoming more difficult.
Gamma Arietis	4·2, 4·4	8	000	Very easy.
Theta Aurigæ	2·7, 7·2	3	330	Stiff test for 3-in. OG.
Delta Boötis	3·2, 7·4	105	079	Fixed.
Epsilon Boötis	3·0, 6·3	2·8	340	Yellow, blue. Fine pair.
Kappa Boötis	5·1, 7·2	13	237	Easy.
Zeta Cancri	5·6, 6·1	5·6	082	
Iota Cancri	4·4, 6·5	31	307	Easy. Yellow, blue.
Alpha Canum Venat.	3·2, 5·7	20	228	Yellowish, bluish. Easy.
Alpha Capricorni	3·2, 4·2	376	291	Naked-eye pair. Alpha^2 again double.
Eta Cassiopeiæ	3·7, 7·4	11	298	Creamy, bluish. Easy.
Beta Cephei	3·3, 8·0	14	250	
Delta Cephei	var, 7·5	41	192	Very easy.
Xi Cephei	4·7, 6·5	8	270	Reasonably easy.
Gamma Ceti	3·7, 6·2	3	300	Not too easy.
Zeta Coronæ Borealis	4·0, 4·9	6·3	304	
Delta Corvi	3·0, 8·5	24	212	
Beta Cygni	3·0, 5·3	35	055	Yellow, green. Glorious.
61 Cygni	5·3, 5·9	25	150	
Gamma Delphini	4·0, 5·0	10	265	Yellow, greenish. Easy.
Nu Draconis	4·6, 4·6	62	312	Naked-eye pair.
Alpha Geminorum	2·0, 2·8	2	151	Castor. Becoming easier.
Delta Geminorum	3·2, 8·2	6·5	120	
Alpha Herculis	var, 6·1	4·5	110	Red, green.
Delta Herculis	3·0, 7·5	11	208	Optical double.
Zeta Herculis	3·0, 6·5	1·4	300	Fine, rapid binary.
Gamma Leonis	2·6, 3·8	4·3	121	Binary; period 400 years.
Alpha Lyræ	0·0, 10·5	60	180	Vega. Optical; B faint.
Epsilon Lyræ	4·6, 6·3	3	005	Quadruple. Both pairs
	4·9, 5·2	2·3	111	separable in 3-in. OG.
Zeta Lyræ	4·2, 5·5	44	150	Fixed. Easy double.
Beta Orionis	0·1, 6·7	9·5	205	Rigel. Can be split with 3-in.
Iota Orionis	3·2, 7·3	11	140	
Theta Orionis	6·0, 7·0			The famous Trapezium in
	7·5, 8,0			M.42.
Sigma Orionis	4·0, 7·0	11·1	236	Quadruple. D is rather
	7·5, 10·0	12·9	085	faint in small apertures.
Zeta Orionis	1·9, 5·0	3	160	
Eta Persei	4·0, 8·5	8·5	300	Yellow, bluish
Alpha Piscium	4·3, 5·3	1·9	291	
Alpha Scorpii	0·9, 6·8	3	275	Antares. Red, green.

Name	*Magnitudes*	*Separation,"*	*Position angle, deg.*	*Remarks*
Nu Scorpii	4·2, 6·5	42	336	
Theta Serpentis	4·1, 4·1	23	103	Very easy.
Alpha Tauri	0·8, 11·2	130	032	Aldebaran. Wide, but B is very faint in small telescopes.
Zeta Ursæ Majoris	2·3, 4·2	14·5	150	Mizar. Very easy. Naked-eye pair with Alcor.
Alpha Ursæ Minoris	2·0, 9·0	18·3	217	Polaris. Can be seen with 3-in.
Gamma Virginis	3·6, 3·7	4·8	305	Binary; period 180 yrs. Closing.
Theta Virginis	4·0, 9·0	7	340	Not too easy.

Some Interesting Clusters and Nebulæ

Object	R.A. *h*	*m*	Dec. °	′	*Remarks*
M.31 Andromedæ	00	40·7	+41	05	Great Galaxy, visible to naked eye.
H.VIII 78 Cassiopeiæ	00	41·3	+61	36	Fine cluster, between Gamma and Kappa Cassiopeiæ.
M.33 Trianguli	01	31·8	+30	28	Spiral. Difficult with small apertures.
H.VI 33–4 Persei	02	18·3	+56	59	Double cluster; Sword-handle.
M.1 Tauri	05	32·3	+22	00	Crab Nebula, near Zeta Tauri.
M.42 Orionis	05	33·4	—05	24	Great Nebula. Contains the famous Trapezium, Theta Orionis.
M.35 Geminorum	06	06·5	+24	21	Open cluster near Eta Geminorum.
H.VII 2 Monocerotis	06	30·7	+04	53	Open cluster, just visible to naked eye.
M.41 Canis Majoris	06	45·5	—20	42	Open cluster, just visible to naked eye.
M.44 Cancri	08	38	+20	07	Præsepe. Open cluster near Delta Cancri. Visible to naked eye.
M.97 Ursæ Majoris	11	12·6	+55	13	Owl Nebula, diameter 3′. Planetary.
M.3 Canum Venaticorum	13	40·6	+28	34	Bright globular.
M.80 Scorpionis	16	14·9	—22	53	Globular, between Antares and Beta Scorpionis.
M.4 Scorpionis	16	21·5	—26	26	Open cluster close to Antares.
M.13 Herculis	16	40	+36	31	Globular. Just visible to naked eye.
M.92 Herculis	17	16·1	+43	11	Globular. Between Iota and Eta Herculis.
M.7 Scorpionis	17	51·6	—34	48	Fine open cluster. Very low in England.
M.23 Sagittarii	17	54·8	—19	01	Open cluster nearly 50′ in diameter.
H.VI 37 Draconis	17	58·6	+66	38	Bright planetary.
M.8 Sagittarii	18	01·4	—24	23	Lagoon Nebula. Gaseous. Just visible with naked eye.
NGC 6572 Ophiuchi	18	10·9	+06	50	Bright planetary, between Beta Ophiuchi and Zeta Aquilæ.
M.17 Sagittarii	18	18·8	—16	12	Omega Nebula. Gaseous. Large and bright.
M.11 Scuti	18	49·0	—06	19	Wild Duck. Bright open cluster.
M.57 Lyræ	18	52·6	+32	59	Ring Nebula. Brightest of planetaries.
M.27 Vulpeculæ	19	58·1	+22	37	Dumb-bell Nebula, near Gamma Sagittæ.
H.IV 1 Aquarii	21	02·1	—11	31	Bright planetary near Nu Aquarii.
M.15 Pegasi	21	28·3	+12	01	Bright globular, near Epsilon Pegasi.
M.39 Cygni	21	31·0	+48	17	Open cluster between Deneb and Alpha Lacertæ. Well seen with low powers.

PART FOUR

Miscellaneous

Astronomical Societies

The advantages of joining an astronomical society are obvious enough. Full information about national and local Societies was given in the 1967 *Yearbook*; a condensed list, suitably brought up to date, is given below.

Name	*Secretarial Address*	*Yearly Subscription* § = members under 18, or 'juniors'	*Meeting Time and Place*
British Astronomical Association	303 Bath Road, Hounslow West, Middlesex (Miss Lydia A. Brown)	45*s* (§30*s*)	Burlington House, Piccadilly Last Wed. each month (Oct–June)
Irish Astronomical Society:			
Belfast Centre	35 Ardenvohr Road, Belfast (D. Beesley)	20*s* (§10*s*)	Fortnightly. Queen's University, Belfast
Dublin Centre	St Fintan's Cottage, Carrickbrack Road, Sutton, County Dublin (F. Murphy)	20*s* (§10*s*)	Fortnightly University College, Earlsfield Terrace, Dublin
Armagh Centre	The Royal School, Armagh (J. Perrott)	20*s* (§5*s*)	Monthly The Planetarium, Armagh
North-West Centre	Magee University College, Londonderry (Professor W. J. Guthrie)		
Junior Astronomical Society	17 Chanctonbury Chase, Redhill, Surrey (D. Beglan)	15*s*	Caxton Hall, London S.W.1 Quarterly
Altrincham and District Astronomical Society	33 Edale Grove, Sale, Cheshire (F. W. Talbot)	5*s*	Park Road Library, Timperly 3rd Friday of each month
Aylesbury Astronomical Society	9 Elm Close, Butler's Cross, Aylesbury (N. Neale)	20*s*	As arranged
Birmingham Astronomical Society	17 Hannafore Road, Edgbaston, (W. E. Marsh)	20*s* (§5*s*)	Birmingham and Midland Institute Monthly
Bristol Astronomical Society	12 Lambley Road, Bristol 5 (S. J. Williams)	20*s*	Lecture Theatre, Bristol University 3rd Friday each month, Sept–May
Caithness and Dounreay Astronomical Society	Room 31, Ormlie Lodge, Thurso, Scotland (Miss M. J. A. Clark)	20*s*	Fortnightly
Cambrian Astronomical Society	57 Park Avenue, Whitchurch, Cardiff (R. W. Skelly and W. H. Sutherland)	15*s* (§7*s* 6*d*)	Fortnightly, Friday evenings, Oct.–June, in Cardiff
Cambridge Astronomical Society	5 Haggis Gap, Fulbourn (S. R. Whistler)	21*s* (§7*s* 6*d*)	7 Brooklands Avenue, Cambridge 2nd Mon. each month, Oct.–July

Name	*Secretarial Address*	*Yearly Subscription* § = members under 18, or 'juniors'	*Meeting Time and Place*
Chester Society of Natural Science, Literature and Art	8 Guy Lane, Waverton, nr. Chester (Mrs N. Hoskyns)	—	Grosvenor Museum, Chester Fortnightly
Chesterfield Astronomical Society	10 George Street, Brimington, Chesterfield (Mrs M. E. Garrod)	15*s*	Barnett Observatory, Newbold Each Friday
Clackmannanshire Astronomical Society	9 Deer Park, Sauchie, Alloa (J. Cluckie)	20*s*	St Mary's School, Alloa. Monthly, 3rd Friday, Sept.–May
Crawley Astronomical Society	Crawley College of Further Education, Sussex (F. D. Cooper)	7*s* 6*d*	Crawley College of Further Education Monthly
Crayford Manor House Astronomical Society	Manor House Centre, Crayford, Kent (R. H. Chambers)	None	Manor House Centre, Crayford Monthly during term-time
Dundee Astronomical Society	4 Finlaggan Place, Dundee Scotland (D. Gavine)	10*s* (§5*s*)	Mills Observatory Dundee Fortnightly in the winter
Eastbourne Astronomical Society	80 Ringwood Road, Eastbourne, Sussex (W. O. Tutt)	21*s* (§10*s* 6*d*)	As arranged Monthly
East Lancashire Astronomical Society	95 Accrington Road, Blackburn (L. Willan)	20*s* (§7*s* 6*d*)	Longridge Observatory, Preston
Astronomical Society of Edinburgh	126 W. Saville Terrace, Edinburgh 9, Scotland (N. G. Matthew)	20*s*	Calton Hill Observatory, Edinburgh Monthly
Ewell Astronomical Society	11 Elmwood Drive, Ewell, Surrey (J. Bentley)	20*s* (§10*s*)	Pitt House, Ewell, Surrey 2nd Tuesday of each month
Fellowship of Junior Astronomers, Edinburgh	58 Ogilvie Terrace, Edinburgh 11, Scotland (Miss Edith McLean)	7*s* 6*d*	Calton Hill Observatory, Edinburgh 2nd Sat. each month, Sept.–June
Fylde Astronomical Society	115 Abercrombie Road, Fleetwood, Lancs (P. P. Cuffe)	10*s* (§5*s*)	Nautical College, Fleetwood 1st Thursday of each month, Sept.–May inclusive
Astronomical Society of Glasgow	164 Mugdock Road, Milngavie, Glasgow, Scotland (N. M. Orr)	10*s*	Roy. Coll. Science and Tech., Glasgow 3rd Thur. each month, Sept.–April
Leeds Astronomical Society	Maths. Dept., The University, Leeds 2 (B. L. Meek)	10*s* (§5*s*)	Leeds University Six annually
Leicester Astronomical Society	49 Bringhurst Road, Leicester (C. Shuttlewood)	21*s* (§7*s* 6*d*)	Leicester Museum and Art Gallery Monthly
Lincoln Astronomical Society	344 Brant Road, Lincoln (P. Hammerton)	20*s* (§5*s*)	Lincoln YMCA Hall 1st Tue. each month
Liverpool Astronomical Society	135 St Michael's Road, Great Crosby, Liverpool 23 (J. E. Abrahams)	15*s* (§5*s*)	Royal Institution, Liverpool Monthly

Name	*Secretarial Address*	*Yearly Subscription* § = members under 18, or 'juniors'	*Meeting Time and Place*
Maidenhead Astronomy Group	129 Fane Way, Maidenhead, Berkshire (S. A. H. Roper)	10*s* (§2*s* 6*d*)	Maidenhead Grammar School Once every 3 weeks
Manchester Astronomical Society	Cragside, Cliff Avenue Summerseat, Bury (Alan Whittaker)	20*s* (§10*s*)	Godlee Observatory, Manchester 1 Weekly
Newcastle-on-Tyne Astronomical Society	30 Kew Gardens, Whitley Bay, Northumberland (G. E. Manville)	20*s*	Botany Lecture Theatre, Newcastle University Monthly, Sept.–April
Nottingham Astronomical Society	18 Naseby Close, Heathfield, Nottingham (C. Swift)	25*s*	Monthly
Oxshott Astronomical Group	Norman Cottage, Pond Piece, Sheath Lane, Oxshott, Surrey (E. H. Noon)	10*s*	Oxshott Village Centre 1st Wed. each month Sept.–May
Paisley Astronomical Society	14 Cheviot Avenue, Barrhead, Glasgow (Mrs J. Holms)	20*s* (full), 10*s* (associate) (half subscription for those under 21)	Coats Observatory, 49 Oakshaw Street, Paisley Monthly
Plymouth Astronomical Society	5 Woodside, Lipson, Plymouth (Lawrence Harris)		Plymouth College of Technology, Tavistock Road, Plymouth Monthly
Preston and District Astronomical Society	35 Bispham Road, Carleton, Poulton-le-Fylde, Lancs (C. Lynch)	20*s* (§5*s*)	Chamber of Commerce, 49a Fishergate, Preston 3rd Mon. each month, Sept.–May
Salisbury Plain Astronomical Society	St George's Cottage Orcheston Salisbury, Wilts. (R. J. D. Nias)	10*s* (§5*s*)	St George's Rectory, Orcheston Quarterly
Sidereal Society	Flat 2, 11 Wellington Road, Brighton, Sussex (Mrs M. L. Cohen)	20*s* (§10*s*)	6 Brunswick Terrace, Hove, Sussex Each Wed., 7.30–9.30
Slough Astronomical Society	The Elms, Odds Farm, Green Common Lane, Wooburn Common, High Wycombe, Bucks (E. Shilton)	20*s*	Monthly
Southampton Astronomical Society	13 Luccombe Place, Shirley, Southampton (F. G. H. Cunningham)	20*s* (§10*s*)	Polygon Hotel, Southampton 2nd Thur. each month Sept.–May
Stoke-on-Trent Astronomical Society	19 Engelsea Avenue, Weston Coyney, Stoke (T. F. Stringer)	20*s*	Hanley, near Stoke-on-Trent Monthly
Swansea Astronomical Society	77 Craiglwyd Road, Cockett, Swansea (R. E. Roberts)	20*s*	As arranged
Torbay Astronomical Society	4 Heath Rise, Brixham, Devon (Miss A. Longman)	15*s* (§5*s*)	Quay Tor Hotel, Scarborough Road, Torquay Monthly
Waltham Forest and District Junior Astronomy Club	24 Fulbourne Road, Walthamstow, London E17 (B. Crawford)	10*s*	24 Fulbourne Road, Walthamstow, London E17 Fortnightly (Mondays)
Warrington Astronomical Society	2 Dale Avenue, Appleton, Warrington (B. P. Rees)	20*s*	Central Library, Museum Street, Warrington, Lancs Monthly. Sept.–May

Warwickshire Astronomical Society	20 Humber Road, Coventry, Warwickshire (R. D. Wood)	80*s*	20 Humber Road, Coventry Each Tuesday
Wolverhampton Astronomical Society	Garwick, 8 Holme Mill, Fordhouses, Wolverhampton (M. Astley)	20*s*	38 Tettenhall Road, Wolverhampton Alternate Mon., Sept.–April
Wyvern Astronomical Society	2 Howcroft, Churchdown Gloucester, (A. F. Edwards)	15*s* (§5*s*)	Clubhouse, Churcham Last Frid. of each month except Aug.
York Astronomical Society	97 Carr Lane, Acomb, York (R. Emmerson)	20*s* (§5*s*)	As arranged Monthly, Sept.–May

It is possible that this list of local societies may not be quite complete. If any have been omitted, the secretaries concerned are invited to write to the Editor (c/o Messrs. Eyre & Spottiswoode (Publishers), Ltd, 11 New Fetter Lane, London EC4).

Some Recent Books

John Kepler, by Angus Armitage. (Faber & Faber, 1966.) A most informative and readable account of the life and work of one of the greatest of all astronomers.

Facing the Universe, by V. A. Firsoff. (Sidgwick & Jackson, 1966.) Semi-technical, though mathematics are separated into an Appendix. The author gives a general account of cosmological problems, together with his reasons for doubting whether the Universe is really in a state of expansion.

Observing Earth Satellites, by Desmond King-Hele. (Macmillan, 1966.) A full account of this subject, by Britain's leading 'satellite-hunter'; strongly recommended to all who are interested in this branch of research.

The Amateur Astronomer's Glossary, by Patrick Moore (Lutterworth Press, 1967). A 'dictionary of astronomy', in which all common terms are explained.

Craters of the Moon, by Patrick Moore and Peter J. Cattermole (Lutterworth Press, 1967). The problem of the origin of lunar craters, approached from the observational and geological point of view.

Starlight Nights, by Leslie Peltier (Macmillan, 1966). The autobiography of the man who is widely regarded as the world's leading amateur astronomer.

The Universe, by Colin A. Ronan (Oxford University Press, 1966). An introduction to astronomy written for young readers, illustrated by coloured paintings by David A. Hardy.

Yearbook of Astronomy 1968

Editor: Patrick Moore

This Yearbook has been specially designed for the amateur astronomer and, once again, the new edition has been completely revised. The notes and data for 1968 have been entirely rewritten and a new series of articles included.

We have kept to our policy of presenting articles on a wide range of subjects. There are two articles on the Moon and two on meteorites. Other articles deal with the Sun, the Hertzsprung-Russell diagram, the construction of a simple refractor, inter-stellar dust, and the spiral structure in galaxies. There is, of course, also Patrick Moore's article on recent advances in astronomy.

The section for stellar observers includes this year an article on variable stars as well as details of interesting double stars and clusters and nebulae suitable for telescope observation. A full list of societies that the amateur astronomer can join is also given.

The Yearbook is of great value to all interested in Astronomy, particularly to the amateur who likes to look out for astronomical events.

The illustration on the front of the jacket is of a large and intricate sunspot group taken by W. M. Baxter on 31st August, 1966; a circle shows the Earth to the same scale.

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